AD-A062 518 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/2
CLIMATIC SURVEY AT CRREL IN ASSOCIATION WITH THE LAND TREATMENT--ETC(U)
NOV 78 M A BILELLO, R E BATES
UNCLASSIFIED CRREL-SR-78-21 NL

1 OF 1
AD
A062518

END
DATE
FILMED
3-79
DDC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Special Report 78-21

November 1978

CLIMATIC SURVEY AT CRREL IN ASSOCIATION WITH THE LAND TREATMENT PROJECT

Michael A. Bilello and Roy E. Bates

DEPARTMENT OF THE ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
CORPS OF ENGINEERS
HANOVER, NEW HAMPSHIRE 03755

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 9 Special Report 78-21	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) 6 CLIMATIC SURVEY AT CRREL IN ASSOCIATION WITH THE LAND TREATMENT PROJECT,		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Michael A. Bilello and Roy E. Bates		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS 31282
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 11 November 1978
		13. NUMBER OF PAGES 39
14. MONITORING AGENCY NAME & ADDRESS(*If different from Controlling Office*) 14 CRREL-SR-78-21		15. SECURITY CLASS. (*of this report*) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

12 42p.

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Cold weather operations
Land waste disposal
Meteorological data
Wastewater treatment

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

During 1972, six test cells were constructed at CRREL for the purpose of studying application of wastewater on various soil types and vegetation. In conjunction with this program, a meteorological observing station was established in order to obtain basic information on the climate proximate to the test cells. This report describes the equipment and its installation, and provides a daily tabulation of the following observed parameters: maximum and minimum air temperatures, relative humidity, dew point, wind speed and direction, precipitation amounts, depth of snow on the ground, solar radiation and pan evaporation. The meteorological data collected during the period starting 1 October 1972 to 31 March 1974 were then summarized and the results are presented in a series of

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified 1B

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

037100

20. Abstract (cont'd)

graphs and line diagrams. The meteorological parameters recorded at CRREL were then examined to determine how weather can constrain or help year-round operation of wastewater application to the land. The positive and negative effects of air temperature, precipitation, wind speed, evaporation and snow cover with respect to land treatment of wastewater were evaluated. Although no specific recommendations or conclusions are given, the influences of these climatic elements as observed at the CRREL wastewater site are presented for consideration.

PREFACE

This report was prepared by Michael A. Bilello and Roy E. Bates, Meteorologists, of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by Corps of Engineers Civil Works Project CWIS 31282, *Techniques for Land Treatment of Wastewater.*

Antonio J. Palazzo, John R. Bouzoun, C. James Martel, and Dr. Harlan L. McKim of CRREL technically reviewed the manuscript of this report. The CRREL Meteorological Detachment from the Maynard, Massachusetts, Meteorological Team, U.S. Army Atmospheric Sciences Laboratory, acquired the data and published the monthly meteorological reports. The encouragement and suggestions provided by Sherwood Reed and Dr. George Ashton during the preparation of this report are appreciated.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

CONTENTS

ILLUSTRATIONS

TABLES

CLIMATIC SURVEY AT CRREL IN ASSOCIATION WITH THE LAND TREATMENT PROJECT

Michael A. Bilello and Roy E. Bates

INTRODUCTION

In CRREL Special Report 171, *Wastewater management by disposal on the land* (Reed et al. 1972), a technical assessment of land disposal methodologies with respect to several different disciplines was conducted. The report showed that for year-round operation in areas with subfreezing winter temperatures, the following meteorological parameters should be considered: air temperature, precipitation, wind speed and direction, evaporation, relative humidity, radiation, and snowfall amount. These allow interpretation of winter surface conditions, such as the depth and physical properties of the snow cover and the formation of ice on the ground, which may result from the freezing of applied wastewater and from the thawing and freezing of winter precipitation.

During 1972, six test cells (Fig. 1) were constructed at CRREL for the purpose of studying application of wastewater on various soil types and vegetation. A program was initiated to obtain basic information on the climate proximate to the test cells. This report describes the equipment used and its installation, and provides summarized results of the collected climatic data. Meteorological considerations for the operation of wastewater treatment systems are presented in reference to the operation of the CRREL test program.

METEOROLOGICAL DATA ACQUISITION

Meteorological instrumentation

Temporary installation of meteorological instruments to measure air temperature, precipitation, wind, and relative humidity was accomplished during September and October 1972 in an open field west of the main CRREL building. After construction of the wastewater test cells was completed, the equipment was moved adjacent to the test cells, and additional observations, such as those for evaporation and solar radiation, were started in July 1973. The locations of the meteorological equipment at both observation sites are presented in Figure 1. A photograph of the main meteorological installation site and a small building (completed in October 1973) used to shelter the recorders is shown in Figure 2.

Following is a listing of the instruments installed.

1. An instrument shelter containing maximum and minimum thermometers and a hygrothermograph to continuously record the air temperature (°F) and relative humidity (%).
2. A standard 8-in. recording rain gage in which an antifreeze liquid is added in winter to melt and record snowfall in equivalent amounts of water (in.). A snow stake is located near this

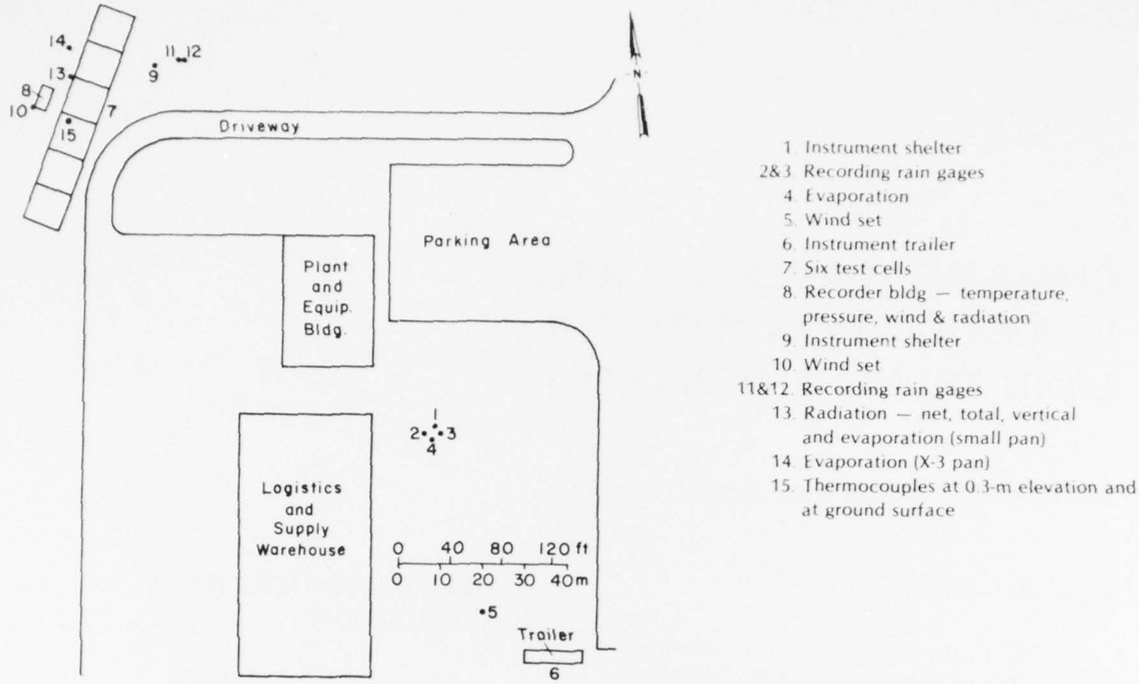

Figure 1. Location of meteorological instruments at CRREL (1-6 were in operation from October 1972 through July 1973, and 8-15 from July 1973 onward).

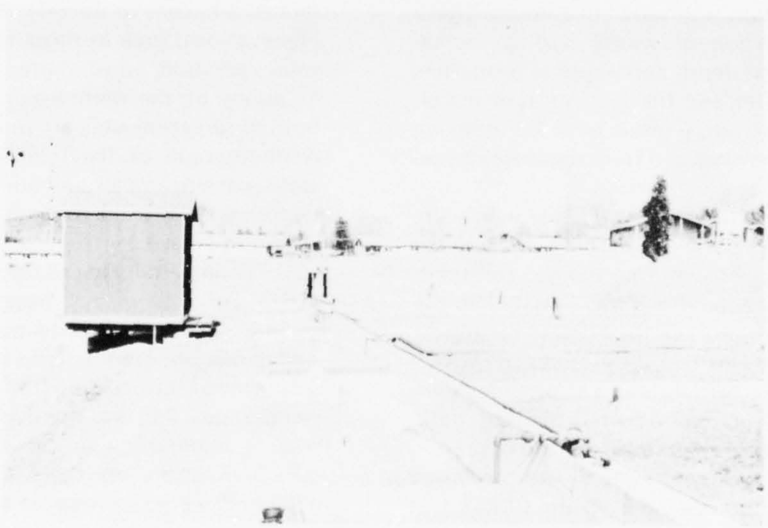

Figure 2. View of meteorological installation and wastewater test cells.

gage to measure the depth of snow on the ground (in).

3. Wind speed and direction equipment from which average hourly speeds, peak gusts (mph) and direction to 16 points of the compass are obtained and continuously recorded.

4. A vertical Eppley pyrheliometer to measure incoming solar radiation falling on a horizontal plane. Hourly average values of solar radiation in langleys (g-cal cm^{-2} h^{-1}) are obtained from this continuously recording instrument.

5. A National Weather Service experimental insulated evaporation pan (called a modified X-3 pan) installed next to the test cells, and a continuously recording Lambrecht evaporation instrument located in one of the test cells. This equipment provides daily and hourly amounts of water (mm) evaporating from an exposed water surface.

6. A two-point recording thermograph to obtain continuous temperature (°C) measurements at the ground/air (or ground/snow) interface and 0.3 m above the surface at the test cells.

Monthly meteorological summary data booklets have been assembled and are available at CRREL. These booklets contain hourly summaries of the weather data collected on this project. Eighteen months of these data (from October 1972 through March 1974) were compiled and tabulated on a daily basis (App. A). This information was summarized, and the results obtained for each of the observed meteorological parameters are described in the following sections.

Air temperature

Mean monthly air temperatures computed from the daily values between October 1972 and March 1974 (App. A) are plotted and compared with the long-term* average monthly air temperature in Figure 3a. This figure shows that the winters of 1972-73 and 1973-74 were both warmer than normal, and that the temperatures from April to November 1973 were near normal. A similar analysis was made using the mean daily maximum and minimum temperatures for the same period (Fig. 3b); this confirms the results shown in Figure 3a and also shows that the average *minimum* air temperatures observed at CRREL during both winters were warmer than normal. However, inspection of later records indicates that average air temperatures in Hanover during more recent years have increased. For example, the average annual air temperature for the period of record used in Figures 3a and 3b (1906-1952) was 43.4°F, whereas during the decennial of 1951-1960 the average annual temperature was 45.3°F. In comparison, the average annual temperature for the year 1973 at CRREL was 44.7°F. Consequently, if recent temperature trends are considered, the year 1973 was actually slightly colder than observed during the 1950's. A comparison of the severity of the 1972-73 and the 1973-74 winters with those between 1951 and 1960 was also made. Total freezing degree-days† for the winters of 1972-73 and 1973-74 at CRREL were 1067 and 1200, respectively, whereas the number of average cumulative freezing degree-days for the winter season between 1951 and 1960 at Hanover was 900. Thus, when frost conditions are considered, the two winters under study were colder than the average winters between 1951 and 1960. This evaluation, however, does not show whether the two winter seasons were longer or shorter than normal.

Precipitation

Information on the rate and amount of precipitation in land treatment management is obviously a necessity. Rainfall and water-equivalent amounts of frozen precipitation (such as snowfall and freezing rain), recorded hourly on a weighing rain gage at the CRREL site from October 1972 through March 1974, are presented in Appendix A. The monthly totals for the period of record at CRREL were plotted (Fig. 3c) and compared with the normal monthly precipitation amounts recorded at Hanover during the 30-year period 1931-1960 as given by the U.S. Dept. of Commerce (1964). The results show alternating periods of above and below normal amounts of precipitation occurring at CRREL over the 18 months of study. The cycles consisted of two- or three-month intervals during the first nine months, followed by a five-month period of slightly below normal precipitation from July to November 1973 and a much above

*Long-term in this case is a 46-year period of record for Hanover, New Hampshire, from about 1906 to 1952 (U.S. Dept. of Commerce 1958).

†The degree-day total for any one day equals the difference between the average daily air temperature and 32°F. The value is negative when the average daily air temperature is below 32°F (freezing degree-days), and positive when above 32°F (thawing degree-days).

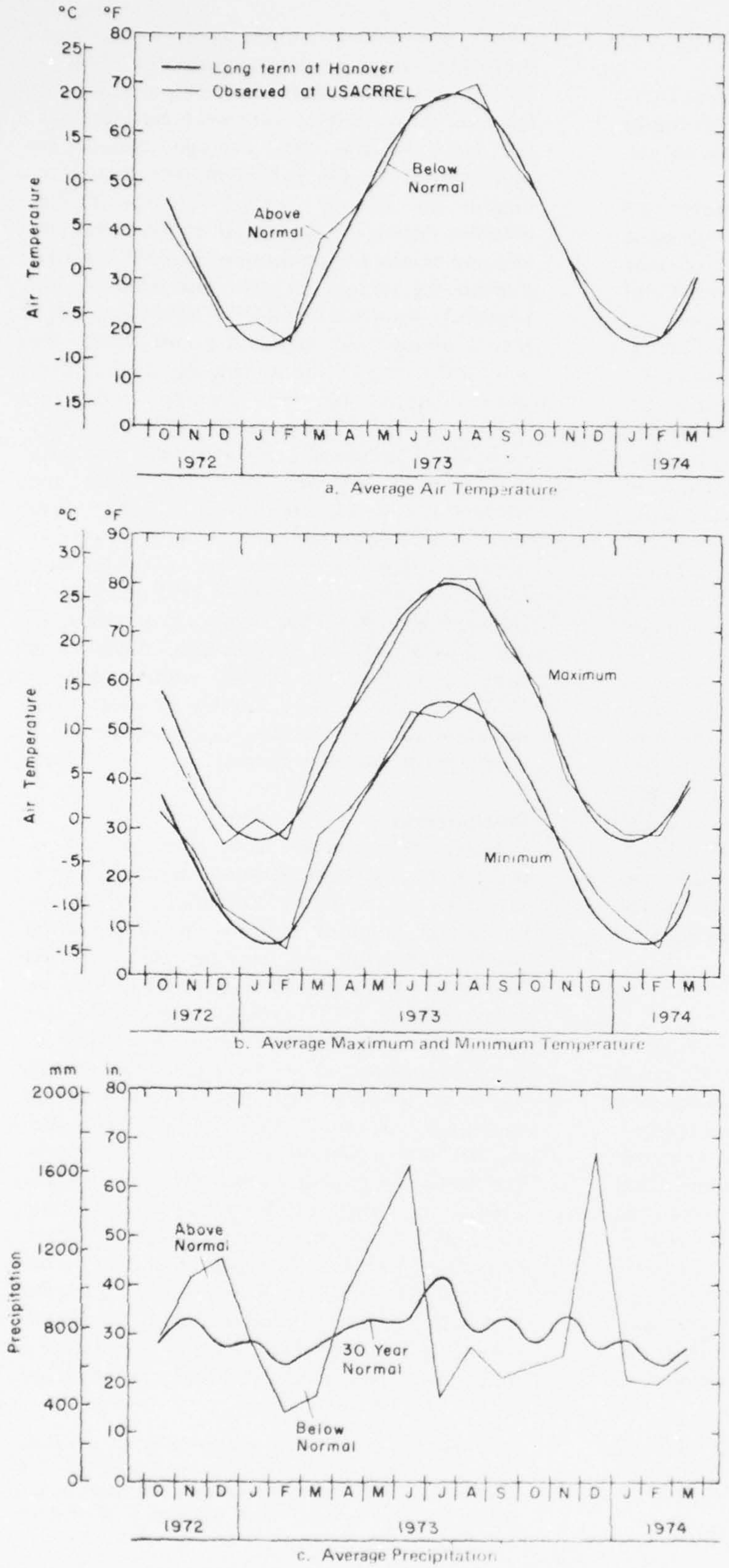

Figure 3. Comparison of observed temperature and precipitation values at CRREL with long term records at Hanover.

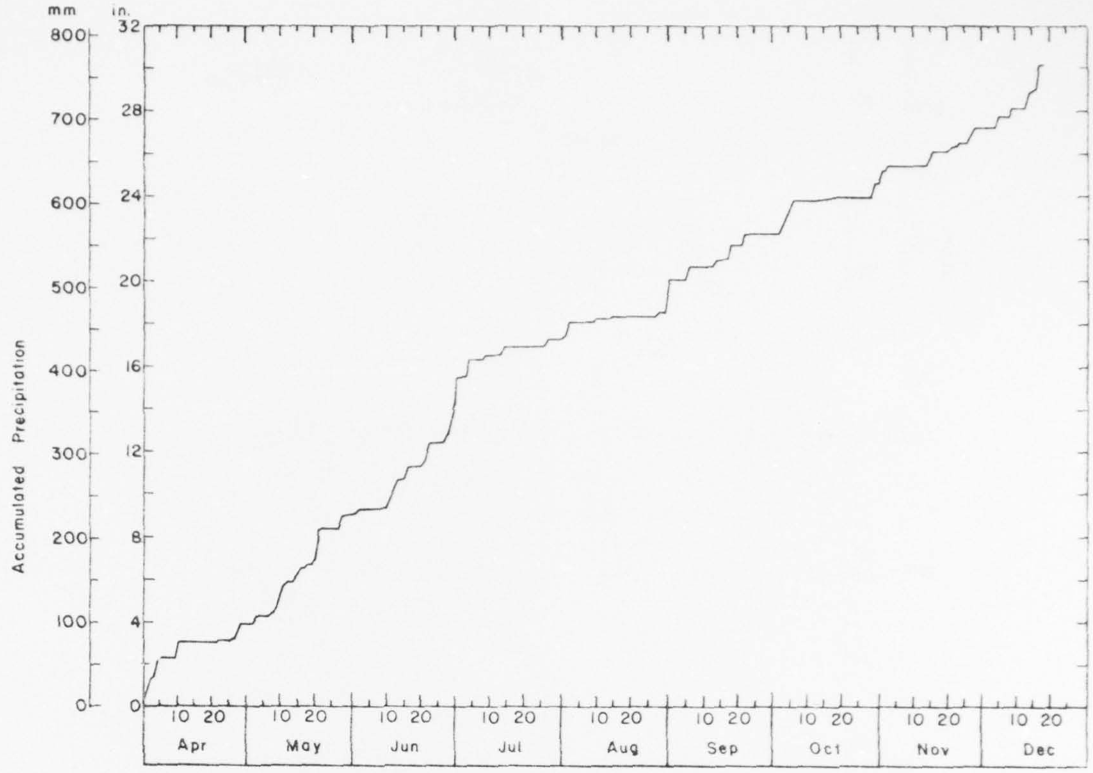

Figure 4. Daily accumulated precipitation amounts at CRREL in 1973 (snowfall converted to water equivalent).

normal period occurring in December 1973. Most of the precipitation during December 1973, incidentally, was in the form of rain. The total annual precipitation in 1973 at CRREL amounted to 39.94 in., which is only slightly above the normal value of 37.30 in. For the warmer period of the year (1 April to 30 September), the observed total precipitation of 22.21 in. at CRREL in 1973 was slightly above normal. More than ⅔ of this amount fell during April, May, and June. Daily amounts of precipitation are also useful in any water balance, water quality or land treatment programs; consequently, these values are also listed in the detailed tabulations presented in Appendix A. A plot of these accumulated daily values of precipitation starting on 1 April and ending on 18 December 1973 is shown in Figure 4. The total amount of accumulated precipitation during this interval was 30.04 in.

The average total annual snowfall amount in Hanover for the 1951-1960 decennial is 81.6 in. (U.S. Dept. of Commerce 1964). Normals for longer records, however, indicate that the total annual snowfall amount for Hanover is closer to 73 in. (U.S. Dept. of Commerce 1958). The accumulated amounts of snowfall and depth of snow on the ground during the winters of 1972-73 and 1973-74 are plotted in Figure 5. Total snowfall during 1972-73 was slightly above normal but was much below normal during the following winter. Comparisons between the depth of snow on the ground and concurrent weather conditions showed that the intervals of accumulation, compaction and ablation closely followed the periods of new snowfall, no snowfall, and warm temperatures, respectively. A maximum snowcover depth of 24 in. was observed during the winter of 1972-73, whereas a maximum depth of only 11 in., as well as periods of no snow on the ground, were noted during the winter of 1973-74.

Although snowfall and snow depths were light during 1973-74, the continued spraying of wastewater during November and December

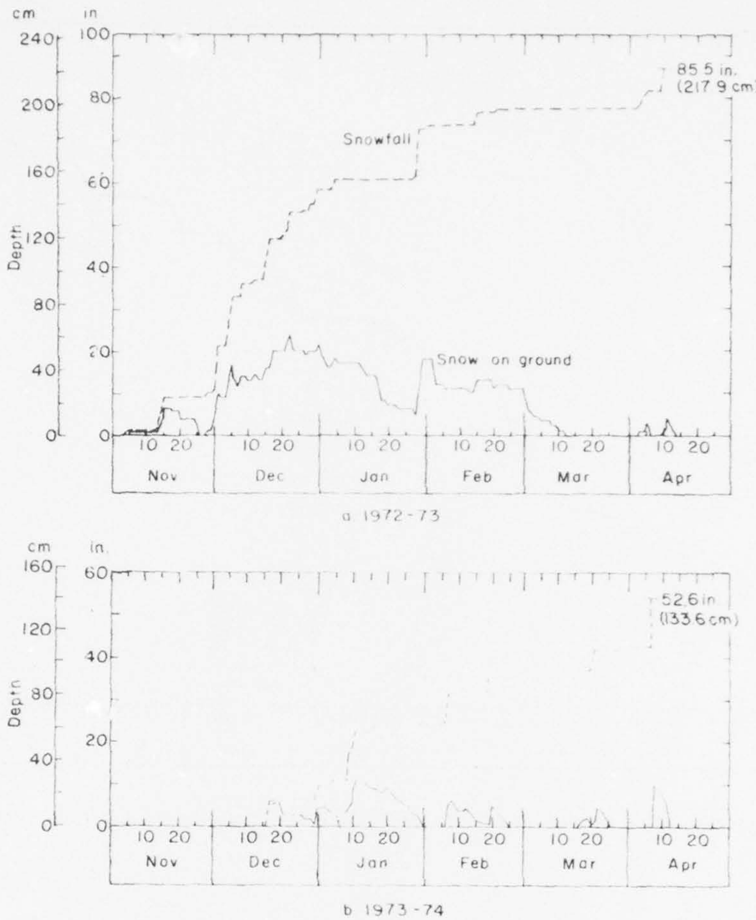

Figure 5. Accumulated snowfall record (Dartmouth Observatory, Hanover, N.H.) and observed depth of snow on the ground at CRREL.

1973 resulted in a substantial buildup of ice on the test cells (see App. B).

Wind speed and direction

Average daily wind speeds and prevailing directions recorded at CRREL during the 18 months of study are given in Appendix A. Monthly averages of these values were computed and the results are shown in Figure 6. The lowest monthly average wind speed (2 mph) was recorded in May 1973 and the highest (7 mph) in March 1974. The mean wind speed at CRREL for the entire observational period was 4.2 mph.

Wind gusts exceeding 20 mph occurred during almost every month; a peak value of 50 mph was observed on two separate days in January 1974. The direction during these events of peak wind was from the south or southwest.

Examination of the predominant wind direction observed on each day (App. A), provided an estimate of the prevailing direction for each month. In some instances two directions were dominant on one day, in which case they were each given half weight in the calculations for developing a wind rose (Fig. 7). The diagram shows that the direction of the wind during the period of study at CRREL was somewhat variable. Synoptic weather patterns strongly affect wind directions; for instance, prefrontal conditions often produce winds from the northeast or southeast, and after frontal passage, the winds shift to the west or southwest. Under other synoptic patterns, the analysis shows a preference for winds to blow from the south-southwest or northwesterly. Although some relationship between preferred wind direction and

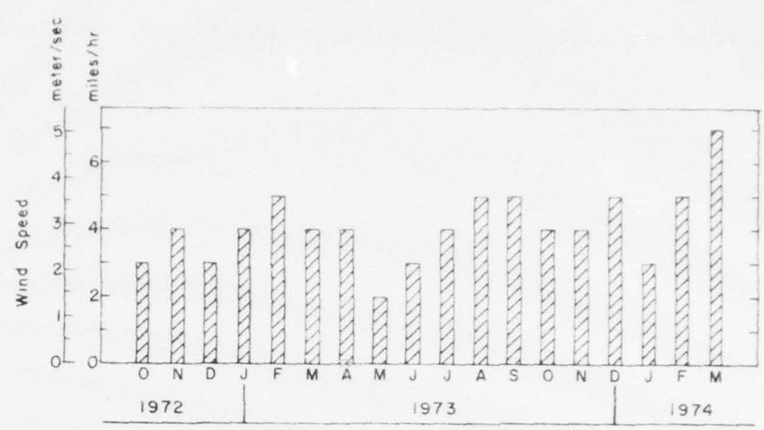

Figure 6. Average monthly wind speeds at CRREL.

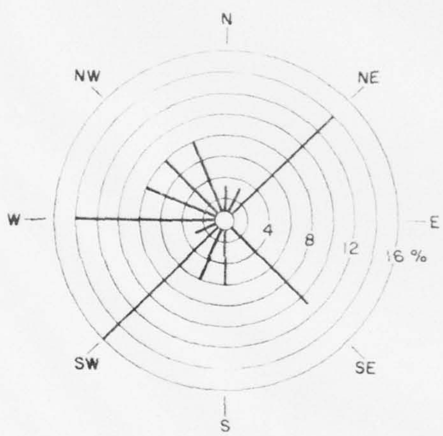

Figure 7. Prevailing wind directions at CRREL (October 1972 through March 1974).

seasons was noted, e.g. northeast winds in winter and southeast in summer, the correlations and length of record were insufficient to justify any positive statements.

Evaporation

Two types of instruments, installed at CRREL on 1 July 1973, measure evaporation adjacent to and within the test cells. One instrument, a portable Lambrecht recording evaporation gage provides a continuous trace so that hourly rates of evaporation can be obtained over a 7-day period. It is located inside the test cells in order to record evaporation losses within the cover of grass. The second instrument, called a modified X-3 evaporation pan (borrowed from the Hydrologic Division, U.S. National Weather Service), is located adjacent to the test cells. This pan is equipped with a stilling well and point gage which are used to accurately measure the change in water level due to evaporation over a 24-hour interval. During periods of rain, the amount of precipitation recorded in the nearby rain gage over the 24 hours of observation is utilized in the evaporation computations. Since the volume of the X-3 pan is much larger than that of the Lambrecht pan, water overflow problems seldom occur with the X-3 pan. Reliable evaporation data during periods of light or no precipitation were recorded by the weighing apparatus in the Lambrecht pan.

The daily amounts of evaporation observed from both pans, as well as the daily precipitation amounts observed from 1 July to 30 November 1973 at CRREL, are given in Table I. The daily evaporation values obtained from the X-3 pan were totaled for each month from July through November 1973 and the results are shown in Figure 8. A maximum monthly evaporation of 150 mm (5.9 in.) occurred in July, and a minimum of 30 mm (1.2 in.) was recorded in November.

Table I. Daily evaporation and precipitation amounts (mm) at CRREL, 1 July — 30 November 1973.

Date	X-3 pan	Lambrecht pan	Precip
July			
1		4.4	
2		5.2	
3	5.2*	0.6	
4			18.0
5			2.3
6	5.0*	4.5*	
7	8.5	10.2	
8	6.0	4.5	
9	6.5	6.2	3.0
10	4.5	4.0	
11	4.5	7.0	
12	12.0	6.9	
13	7.0	5.7	0.5
14	2.5	3.6	9.7
15	5.8	5.8	1.0
16	2.5	1.5	
17	5.0	5.0	
18	4.0	3.6	
19	5.0	5.4	
20	5.0	2.8	
21	4.5	5.6	
22	4.0	7.6	
23	7.0	5.0	
24	7.0	7.0	
25	7.0	5.2	
26	5.0	3.6	
27	3.0	4.2	9.7
28	4.0	6.8	
29		4.2	
30	13.0*	4.8	
31	6.0	5.8	
Total	149.5	146.7	44.2
August			
1	7.7	m	3.3
2	3.2	m	17.5
3	2.0	3.2	
4	5.0	2.0	
5	6.0	7.0	
6	7.0	2.4	
7	3.0	5.2	
8	4.2	4.0	
9	4.0	4.8	
10	5.0	6.1	2.5
11	6.5	m	
12	5.0	4.4	
13	4.5	m	
14	4.0	3.4	
15	0	0.6	1.8
16	0.8	3.9	
17	4.0	4.2	
18	4.0	5.7	
19	5.0	3.8	
20	6.0	m	
21	3.8	3.6	
22	3.6	1.7	1.5
23	3.0	4.7	
24	4.5	5.4	
25	6.0	5.0	
26	4.5	2.6	
27	4.0	m	1.3
28	3.6	5.0	4.6
29	5.5	4.2	
30	5.0	3.0	
31	4.0	m	37.3
Total	134.4	Inc †	69.8
September			
1		m	
2	14.0*	m	
3	3.0	3.5	
4	5.0	3.2	
5	4.0	4.2	
6	4.0	3.0	16.3
7	5.0	m	
8	6.5	m	
9	2.5	1.3	
10	3.0	2.1	
11	4.0	3.2	
12	3.0	3.0	
13	3.0	m	
14	4.0	3.6	8.1
15	0	0	0.3
16	0.5	0.3	
17	3.0	2.3	0.3
18	4.4	3.2	17.3
19	0	0	
20	2.0	2.2	
21	3.0	1.4	
22		4.0	13.2
23	3.7*	0.8	
24	1.0	3.0	
25	1.5	0.6	
26	2.0	2.0	
27	2.0	1.8	
28	2.0	2.2	
29	4.5	3.4	
30	4.5	3.8	
Total	95.1	Inc †	55.5
October			
1	5.0	4.2	
2	3.0	2.2	8.4
3	0	0	13.7
4	1.7	m	6.6
5	0.5	0	11.2
6	2.0	m	
7	3.0	3.7	
8	4.0	m	
9	2.0	1.4	
10	2.0	2.2	
11	1.0	1.6	
12	1.0	1.6	
13	2.0	2.2	
14	2.0	1.4	1.5
15	2.5	1.6	
16	3.0	3.6	
17	2.0	1.8	
18	1.0	1.6	1.5
19	1.5	0	
20	1.5	1.4	1.5
21	0	0	
22	1.5	2.1	
23	1.0	1.5	
24	1.0	1.2	
25	2.0	1.6	
26	0.5	0	
27	1.0	1.2	
28	3.5	2.2	
29	2.5	1.6	1.3
30	0.5	0	15.0
31	0	0	
Total	54.2	Inc †	60.7
November			
1	0	0	15.2
2	1.0	0	1.0
3	3.0		4.3
4	5.5	3.7*	
5	2.0	2.3	
6	2.0	2.5	
7	1.0	0	
8	2.0	2.4	0.5
9	0.5	0.8	
10		2.4	
11		1.4	
12		0.6	
13		0.8	
14		0.3	
15	7.5*	1.3	9.4
16		0	9.1
17		0.7	
18		1.2	
19		0.5	
20		1.8	
21		0.8	0.8
22		0	1.8
23	4.0*	0	
24	0	0	4.3
25	0	0	2.0
26	0	1.0	
27	0	0.4	10.2
28	0	0	6.6
29	0.8	1.2	
30	1.0	1.2	0.5
Total	30.3	27.3	65.7

*Includes evaporation occurring on previous days

†Inc = incomplete

m = missing

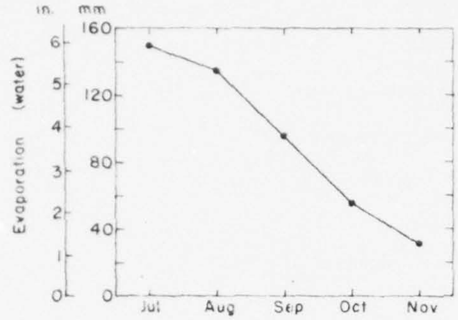

Figure 8. Total monthly evaporation amounts, X-3 experimental insulated evaporation pan at CRREL, 1973.

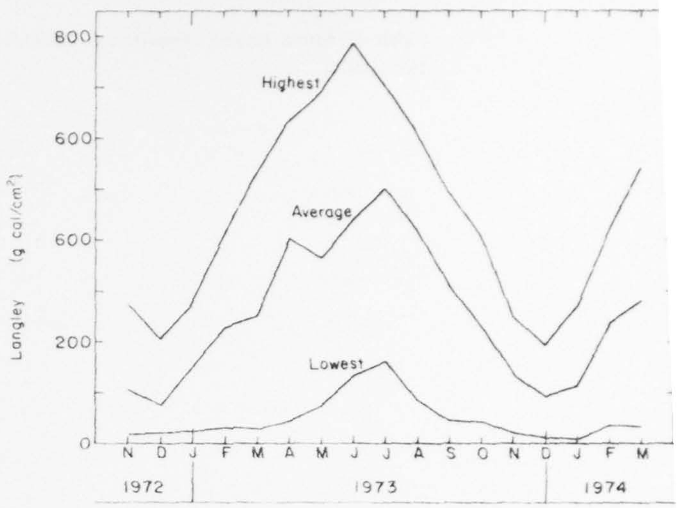

Figure 9. Solar radiation at CRREL.

Solar radiation

Average daily measurements of incoming solar radiation in langleys were obtained over the wastewater test cells with a vertical Epply pyrheliometer. The lowest and highest daily amounts observed during each month and the average monthly values obtained during the period from November 1972 through March 1974 are shown in Figure 9. Highest average values occurred in June and July when daily amounts of 450 to 500 langleys were recorded. However, during these two months the radiation values ranged from 130 on an overcast-rainy day to 790 langleys on a bright-clear day. Minimum radiation values occurred in December when average daily amounts rarely exceeded 100 langleys, and ranged from 10 to 200 langleys each day. During the time period studied here, the calculated mean solar incoming radiation at CRREL was 290 langleys per day.

Surface snow, ice and temperature conditions

Descriptions of major changes in snow and ice conditions on the surface in and near the test cells during the winter of 1973-74 are given in Appendix B. This chronological tabulation includes the types of precipitation observed, the surface condition of the test cells after the spraying of treated wastewater on the snow and frozen ground, and the alternating accumulation and melting of the snow and ice cover.

Snow-cover density observations (g/cm³) were made inside the test cells and in nearby undisturbed areas after new snowfalls or when significant changes in snow-cover properties occurred. These density measurements are listed in Table II. Three distinct snow or snow-ice layers were identified from these observed densities. Undisturbed layers of new snowfall provided density readings of less than 0.20 g/cm³ both outside and inside the test cells until wastewater was applied to the snow. After a period of time the fresh snow layers compacted through natural processes (Bader et al. 1954) and the density gradually increased from about 0.20 to 0.28 g/cm³, thus forming a second type of snow-cover layer. The density values in Table II show that this second type of snow cover is generally uniform both outside and inside the test cells as long as no water is applied to the snow. The third snow density category occurred during December and January after wastewater was sprayed over the snow as it accumulated in the test cells. Water on the snow quickly changed its characteristics, and the resulting snow-ice combination compacted and hardened significantly. The snow-ice densities ranged from 0.42 to 0.70 g/cm³. An unusually warm January thaw in 1974 then melted almost all of this snow-ice layer so that snow cover conditions inside and outside the test cells were similar during the remainder of the winter and following spring.

Table II. Snow cover densities at CRREL for the winter of 1973-1974.

Date	*Undisturbed area* (g/cm^3)	*In test cells* (g/cm^3)
18 December		0.420
19 December		0.720
20 December		0.400
27 December		0.617
31 December	0.133	0.133, new snow on top of ice layer
9 January	0.156	0.600-0.700, old ice from spray
9 January	0.072, new snow	
20 January	0.260	0.260, top layer only
23 January		0.272, top layer only
31 January	Most of old frozen spray crust residual melted	
7 February	0.082	0.082, new snowfall
7 February	0.208	0.235
14 February	0.232	0.238
20 February	0.180	0.180, new snowfall
28 February to 20 March	Not enough snow on ground or plots for measurement	
21 March	0.165	0.165, new snowfall
22 March	0.204	0.204
27 March	Most of snow melted in area and on plots	
9 April	0.188	0.188, new snowfall
10 April	0.220	0.220
11 April	0.252	0.252
16 April	No snow cover, end of measurements 1973-1974	

Average daily snow/ground interface temperatures, average daily air temperatures, and daily snow-cover depths measured near the temperature probes are presented in Figure 10. The snow/ground interface temperatures between 18 December 1973 and 31 January 1974 only ranged from 27° to 31°F when the ground was covered with snow 1 to 8.5 in. deep. The average daily air temperature during the same period ranged from −8 to +43°F, but these high and low values had little influence on the ground temperatures due partly to the insulating layer of snow. However, the cold air temperatures and subsequent shallow snow cover during February 1974 (Fig. 10) resulted in colder snow/ground interface temperatures, which probably caused a greater penetration of frost in the ground. The variable ground temperatures observed at this time also may have been caused by the exposure of the probe to direct sunlight as well as lack of a snow cover for insulation. This solar and noninsulated influence on the surface temperature is confirmed by the close association between the daily changes in the air and ground temperatures (see Fig. 10).

Based on the significant warming period which occurred between 1 and 8 March 1974 (Fig. 10), it is possible that wastewater spraying could have commenced sooner than the reported date of 17 April 1974. However, plant uptake of wastewater constituents would not take place this early in the spring at Hanover, New Hampshire.

CLIMATIC CONSIDERATIONS IN LAND TREATMENT OF WASTEWATER

In any program of land treatment of wastewater, the climate at each site is an important factor to consider (Whiting 1976). Local weather directly influences such factors as the length of the growing season, the soil surface conditions, the gain and loss of water by precipitation and evaporation, etc. In frost-susceptible regions,

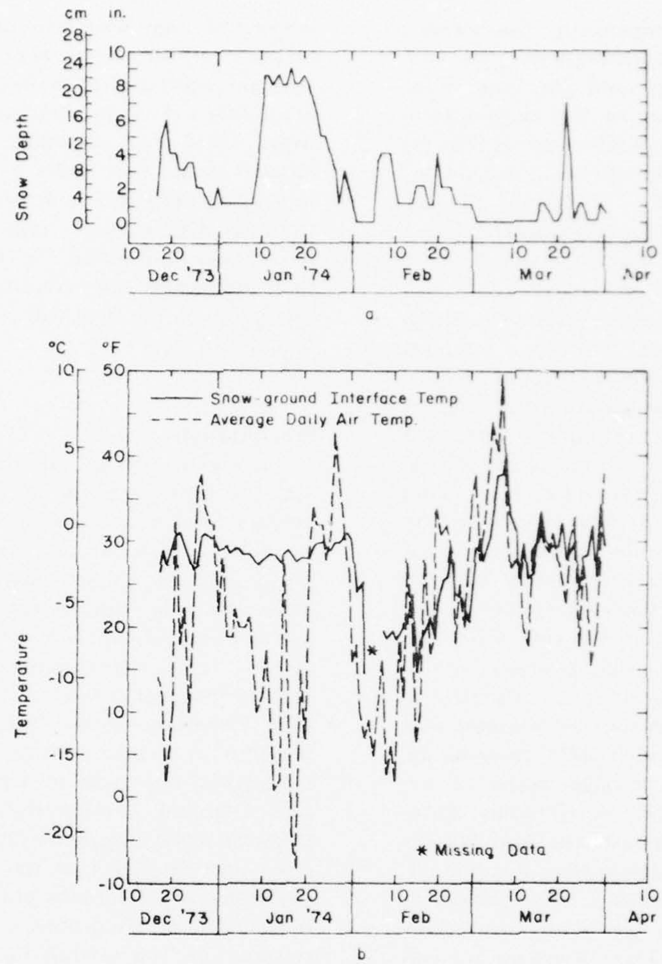

Figure 10. Average snow-ground interface temperature, average daily temperature and observed depth of snow on the ground at CRREL.

specific knowledge of the snow cover and frozen ground is also important. In the following discussion, the meteorological elements recorded at CRREL will be examined to point out possible ways that weather conditions can constrain or help year-round operation of wastewater application to the land. Although no specific recommendations or conclusions are given, climatic parameters and their effects within the context of the requirements for land treatment of wastewater as observed at the CRREL site from October 1972 through March 1974 are presented for possible consideration.

Air temperature

An average air temperature curve similar to that shown for Hanover in Figure 3a provides a good first estimate of the length of the non-frost season, i.e. the probable beginning date of freezing temperatures in late autumn and the start of the thaw season in spring. For example, Figure 3a shows that average daily temperatures of 0°C or less at Hanover can be expected to start in about mid-November and end in mid-March. However, during the last half of November 1973 the air temperatures at CRREL were above normal, indicating that the soil during some years could remain unfrozen beyond the usual time of expected frost. Extension of the application period beyond a predetermined or expected average date should be further considered because the temperature of the wastewater is usually warmer

than the ambient air temperature. Continuous flooding minimizes soil freezing within the soil profile in the early winter, and thus may allow for continued infiltration of the wastewater. However, a study by Jenkins et al. (1978) indicates that satisfactory biochemical oxygen demand (BOD) removal did not occur at soil temperatures below 4°C. Consequently, these critical temperatures should be taken into account during this evaluation.

If temporary release of wastewater (e.g. due to limited storage) by spraying in winter is required or becomes necessary, additional application to the land can be accomplished in several ways. In temperate regions, for example, significant thawing periods in midwinter may permit the occasional release of water directly to the land when and if any cover of snow has melted. In fact, in some cases, considerable infiltration of wastewater in the soils may be possible beneath a protective snow cover which has prevented the surface of the ground from freezing. However, the spraying of wastewater over a snow cover requires special dispensing nozzles, otherwise it may not be effective. When this method was tried at CRREL in December 1973, freezing air temperatures produced a large dome of ice around the experimental, small-radius spray nozzles being used on the test cells (App. B). This mixture of snow and frozen wastewater remained solid until the following thaw period in spring. A description of a type of nozzle used for winter spraying at West Dover, Vermont, is given by Bouzoun (1977). A successful method of wintertime sprinkler distribution of wastewater has also been conducted in the Soviet Union (Shcherbakov 1978). This was achieved by spraying the wastewater away from the sprinkler so that ice buildup did not occur under the sprinkler head.

If winter application of wastewater is planned, information on frost penetration is required to determine the depth at which an underground pipeline system should be laid. Computation of the design freezing index (i.e. coldest winter in either a 10- or 30-year record) is one method which could help provide such information. Instructions on the procedures for calculating this value are given in a U.S. Army technical manual (U.S. Army 1965). However, the freezing index *alone* will not furnish the essential information on the depth of frost in the ground due to 1) the insulating properties of the snow cover, 2) the effects of different types of soil, and 3) the influence of vegetation type and density. The effects of various homogeneous soil types on the rate and depth of frost in the ground is described in another U.S. Army construction manual (U.S. Army 1966). For example, Figure 14 of this manual shows that under a snow-free cover of turf, frost penetration in silty sand after 1500 freezing degree days have accumulated will reach a depth of about 3½ ft. Under similar surface and temperature conditions in well drained sandy gravel, the frost will penetrate to about 5 ft in depth.

Precipitation

The design of an efficient land treatment system must include an evaluation of the average amount and rate of precipitation so that a water balance can be calculated. Depending on various soil, salinity, and plant factors, arid areas generally permit greater application rates per unit area of land than are possible in humid regions. This is due mainly to increased rates of evapotranspiration and evaporation. Information, therefore, on the regional and seasonal distribution of precipitation is important in the design and operation of a land treatment project. Detailed weather data as given in U.S. Department of Commerce (1956, 1959, and 1964) have proven useful in the planning stage to determine which months of the year one can expect critical conditions such as excessive evaporation, low rainfall, high air temperatures, high wind speed, etc.

The rate of rainfall (i.e. its intensity) becomes important when considering storage requirements for excessive runoff. In these instances, reported total daily or monthly precipitation amounts may be misleading because a large percentage of this rainwater may have fallen during one or more high intensity storms. Since thunderstorms produce much of the rain in the summer, for example, the average monthly precipitation amounts as given in the records should be used with caution.

A review of how air temperatures and precipitation affected the winter operation at the CRREL wastewater site during 1973-74 follows. Wastewater application continued during intermittent periods of freezing and thawing temperatures and light snow showers between 21 September and 18 December 1973. Brief intervals of above freezing air temperatures between 27 December 1973 and 31 March 1974 (App. A)

may have permitted occasional midwinter application of wastewater at CRREL, if needed. However, such attempts were not made during this period because the soil remained frozen for most of the winter. Snowfall amounts in the area throughout the winter of 1973-74 were light, and the ground was free of snow by 24 March 1974. However, application of wastewater on the test cells at CRREL did not begin again until 17 April. An earlier start might have been possible if the ground had thawed before 12 April and if the soil had been less saturated (App. B).

Wind speed

The contribution of surface winds to the amount of wastewater that can be applied to the test cells throughout the period of study was investigated. The study showed that the most significant influence occurs during periods of high wind speed in summer because evaporation rates from an open water surface were observed to increase very rapidly at these times. This is particularly true when the moving air is quite dry, as for example on 12 July 1973 at CRREL when a maximum hourly wind speed of 24 mph was recorded and the daytime humidity decreased to a minimum of 36% (App. A). The evaporation from the X-3 pan on this date was 12 mm (0.47 in.). When a land treatment system is designed to apply as much wastewater as possible during the summer months, continuous monitoring of the wind speed and relative humidity is essential because of the resultant increased water losses through evaporation. An association between evaporation and evapotranspiration rates will be discussed later in this section. This close relationship between high evaporation rates and strong winds, however, no longer applies during periods of precipitation or frigid weather.

A study in which the above principle of maximum wastewater application was used, based on crop type and growth stage, was conducted by Hiler et al. (1974). The concept that they used for optimizing water need employs a technique called the stress day index (SDI). The procedure provides a quantitative method for determining the water stress imposed on a crop during its growing season. This crop susceptibility factor (CS) is determined experimentally as the fractional reduction in yield resulting from a fixed water deficit during a given growth stage. The authors also note that other rational irrigation timing approaches have been reviewed by the following investigators (Fleming 1966, Linacre and Till 1969, Jensen et al. 1970, and Hiler et al. 1972). However, it should be noted that the above procedures are used as "system operation" options. In instances where there is a built-in capability to monitor the daily wind, temperature, humidity, and radiation conditions, it may be possible to increase or decrease the application rate accordingly. Generally, elaborate systems such as this are not economical and are instead built and operated on average or extreme monthly, seasonal or annual climatological data. For example, present design procedures consider the worst climatic conditions observed during each month for a 10-year period of record (U.S. Environmental Protection Agency 1977).

Water budget approach

In the introduction of a study conducted by Rouse and Wilson (1972), the authors state, "The water-budget approach* to determining evapotranspiration has the advantages that the necessary measurements can be made quickly, little training or skill is needed on the part of the investigator, and a program can be operated cheaply over long periods of time." In this study, the authors found that the estimation of evapotranspiration from a soil moisture budget approach under an exposed 120- × 210-m field of corn was acceptable (within ±10%) when 1) the time span between the measurements in soil moisture change was at least four days, 2) evapotranspiration rates were high (> 3 mm/day), 3) there was no precipitation, and 4) six or more sites were used to give a spatial average. The study showed that, with simplified field measurements, a reliable account of the water budget will provide results comparable to those obtained from extensive micrometeorological measurements and energy exchange calculations.

The CRREL site is a closed system (except for losses due to evapotranspiration) and therefore offers a means of accurately conducting a water budget study. Since the test cells are enclosed on all sides and at the bottom by concrete, there is no water loss by lateral movement or by deep

* This approach involved the following relationship: $E = r - \Delta s_m - v_d - v_s - s$, where E is evaporation, r is precipitation, Δs_m the volumetric change in soil moisture with time, v_d the net drainage across the terminal depth of measurement, v_s the net water loss from the measurement zone due to lateral subsurface movement, and s the net water loss due to surface runoff (Rouse and Wilson 1972).

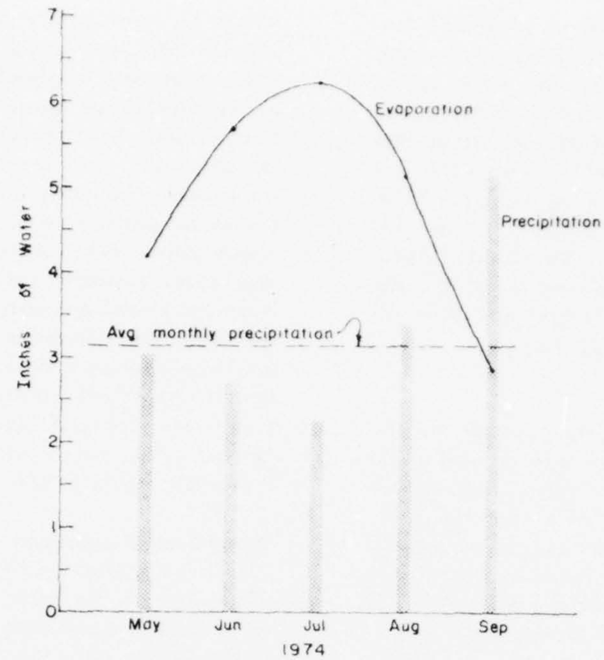

Figure 11. Monthly precipitation and evaporation amounts at CRREL, May-September 1974.

infiltration. In order to conduct such an evaluation of the water budget at the CRREL wastewater installation, the following components should be monitored: 1) the input of precipitation and wastewater amounts for water *gain*, 2) the percolated water collected at the bottom of the test cells for water *loss*, and 3) the amount of water retained in the soil, root systems, and vegetation for water *loss* due to storage. The remaining water losses would be due to evapotranspiration.

A preliminary study conducted at CRREL* has shown that maximum evapotranspiration occurred when small, frequent, and sufficient doses of water were applied so that no decrease in plant transpiration would take place. One large application (one per week for example) equal to all the small doses did not produce equivalent evapotranspiration losses. The soil in this case does not retain all the water because some is lost to percolation. A deficiency in available water then may occur prior to the next application so that evapotranspiration is not sustained at normal (or maximum) rates.

Pan evaporation

An investigation of monthly evaporation amounts obtained from the X-3 experimental pan and the concurrent monthly precipitation amounts for the period 1 May through 30 September 1974 at CRREL was conducted. The results are shown in Figure 11. Note that these dates extend beyond the period of record discussed earlier in this study. Since pan evaporation measurements began in July 1973, data for the entire summer were not available until the following year. The record for 1974, therefore, was used in this analysis. The monthly precipitation amounts observed during the summer of 1974 at CRREL (Fig. 11) show that, except for September when an uncommonly high rainfall occurred, the totals ranged from 2.3 to 3.4 in. These monthly values of observed precipitation coincide with long-term average records which show that the Hanover-Lebanon, New Hampshire, region experiences similar amounts of

*Personal communication, A. Uiga, Metcalf and Eddy, Inc. Palo Alto, California (formerly a sanitary engineer at CRREL), 1978.

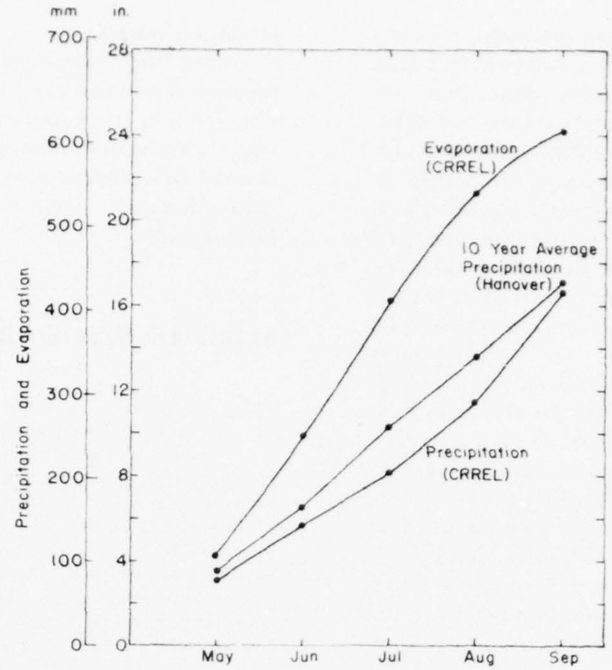

Figure 12. Comparison of accumulated precipitation and evaporation amounts at CRREL, May-September 1974.

precipitation each month throughout the year (U.S. Dept. of Commerce 1964).

Maximum evaporation at CRREL normally occurs during July when slightly more than 6.0 in. of water returns to the atmosphere (Fig. 11). Minimum values occur in winter, but since exposed water surfaces at the CRREL site freeze during most of the period between December and March, snow surface evaporation measurements were not attempted. The accumulated precipitation (16.58 in.) at the wastewater site between 1 May and 30 September 1974 and the water lost to the atmosphere as measured by pan evaporation (24.15 in.) during the same period are shown in Figure 12. This gain and loss of water through natural means show a deficit of over 7.5 in. occurring as a result of evaporation during the five months under study.

Daily monitoring of evaporation rates is probably most useful for application in crop management. For example, Hiler et al. (1974) describe a situation in which the crops are exposed to an extremely high evaporative demand, even though the soil is well irrigated. If evaporative demand exceeds maximum supply rate from the soil, the plant would indicate a water deficit. When the soil is already wet, an appropriate irrigation approach to conserve water, would be, if feasible, to apply a light spray of water to the cropland. Consequently, during meteorological events of strong, dry, and warm winds, the soil could be fully saturated and the crop can still be continuously wetted to reduce the evaporative demand.

Potential evapotranspiration and pan evaporation comparison

Another method in which potential evapotranspiration (PET) rates can be estimated is to consider the association between PET and pan evaporation. In a watershed evapotranspiration study conducted by Saxton et al. (1974), for example, the relationship between PET and both pan evaporation and solar radiation was evaluated. They found that calculated daily values of potential evapotranspiration (PET)

compared more closely with observed amounts of pan evaporation than they did with net radiation. The investigation showed that calculated values of PET depend not only on the net radiation but also on wind run and the vapor pressure deficit. Consequently, they found less scatter in the comparison with pan evaporation than with net radiation because pan evaporation responds to both radiation and the aerodynamic variables. In their summary, the authors state that, "Good correlation of observed daily pan evaporation with calculated daily PET values substantiates the common practice of estimating PET amounts by adjusting observed pan evaporation." In their study, monthly ratio values of PET/pan evaporation determined for three years of observation ranged from about 65 to 80% for the early spring and late autumn months, and from about 80 to 95% for the months May through September. The average seasonal (i.e. April through October) ratio of PET/pan evaporation obtained from the three-year study was 81%. Since pan evaporation data are readily available for many states (U.S. Dept. of Commerce 1955, 1959), utilization of the preceding ratios would be beneficial for estimating evapotranspiration amounts. In fact, the U.S. National Weather Service is now providing daily surface water evaporation reports for the southern Great Plains irrigation farmers (Newton and Wilke 1972). Additional information on the ratio values between pan evaporation and evapotranspiration over various crops is given in a soil conservation handbook (USDA 1964), and in evapotranspiration equations reviewed by Veihmeyer (1964).

If the average May through September PET/pan evaporation ratios of 80 to 95%, as obtained by Saxton et al. (1974), are applied to the 24.15 in. of pan evaporation recorded at CRREL, the total estimated evapotranspiration for the period studied would range from about 19 to 23 in. The difference between PET and pan evaporation amounts (1-4 in.) can be considered to be relatively small when compared with the average total of 55 in. of wastewater which was applied to the test cells over the five-month period. Consequently, installation of elaborate and expensive micrometeorological equipment to measure evapotranspiration rates from the vegetation on the CRREL wastewater cells does not appear to be a useful or necessary alternative.

Literature review

During the course of this investigation a number of recent reports which contain information relating to evaporation or evapotranspiration, wastewater management, water-quality control, or water pollution were obtained. These papers have also been included in the *Selected Bibliography*.

SELECTED BIBLIOGRAPHY

Bader, H., R. Haefeli, E. Bucher, J. Neher, O. Eckel and C. Thams (1954) Snow and its metamorphism. U.S. Army Snow, Ice and Permafrost Research Establishment Translation 14. AD 030965.

Bouzoun, J. (1977) Land treatment of wastewater at West Dover, Vermont. CRREL Special Report 77-33. AD 046300.

Fleming, P.M. (1966) Crop water requirements and irrigation. *Proceedings of World Meteorological Seminar*, Melbourne, Australia, p. 593-618.

Golubev, V.S. (1970) Effect of rainfall and evaporation on the concentration of solutions. *Soviet Hydrology: Selected Papers*, Issue no. 4, 1970.

Hargreaves, G.H. (1974) Estimation of potential and crop evaporation. *Transactions of the American Society of Agricultural Engineers (ASAE)*, vol. 17, no. 4, p. 701-704.

Hargreaves, G.H. (1975) Moisture availability and crop production. *Transactions of the ASAE*, vol. 18, no. 6, p. 980-984.

Heinke, G.W. and B. Deans (1973) Water supply and waste disposal systems for arctic communities. *Journal of the Arctic Institute of North America, Arctic*, vol. 26, no. 2, June 1973.

Hiler, E.A., T.A. Howell and D.G. Bordovsky (1972) Stress day index — A new concept for irrigation timing. In *Proceedings of Optimization of Irrigation and Drainage Systems Conference, American Society of Civil Engineers*, p. 579-595.

Hiler, E.A., T.A. Howell, R.B. Lewis and R.P. Boos (1974) Irrigation timing by the stress day index method. *Transactions of the ASAE*, p. 393-398.

Hillel, D. and Y. Guron (1973) Relation between evapotranspiration rate and maize yield. *Water Resources Research*, vol. 9, no. 3, June.

Jenkins, T.F., C.J. Martel, D.A. Gaskin, D.J. Fisk and H.L. McKim (1978) Performance of overland flow land treatment in cold climates. *Proceedings, International Symposium on Land Treatment of Wastewater*, Hanover, N.H., vol. 2.

Jensen, M.E., D.C.N. Robb and C.E. Franzoy (1970) Scheduling irrigations using climate-crops-soil data. *Journal of the Irrigation and Drainage Div., American Society of Civil Engineers*, vol. 96 (IR 1), p. 25-38.

Johnson, J.F. (1972) Regional wastewater management: A new perspective in environmental planning. *Water Sources Bulletin*, vol. 8, no. 4.

Jones, J.W., R.E. Colwick and E.D. Threadgill (1972) A simulated environmental model of temperature evaporation, rainfall and soil moisture. *Transactions of the ASAE*, vol. 15, no. 2.

Koon, J.E., E.W. Rochester and M.K. Howard (1972) Environmental studies with artificial turf and grass surfaces. *Transactions of the ASAE*, vol. 15, no. 5.

Kuznetsov, V.I. (1970) Characteristics of evaporation from industrial wastewaters. Soviet *Hydrology: Selected Papers*, Issue no. 4.

Linacre, E.T. and M.R. Till (1969) Irrigation timing and amounts. *Journal of the Australian Institute of Agricultural Science*, vol. 35, no. 3, p. 175-196.

Newton, O. and O. Wilke (1972) *Evaporation loss now reported daily*. Publication of the High Plains Underground Water Conservation District No. 1. *The Cross Section*, vol. 18, no. 5.

Reed, S.C., P. Murrmann, F. Koutz, W. Rickard, P. Hunt, T. Buzzell, K. Carey, M. Bilello, S. Buda, K. Guter and C. Sorber (1972) Wastewater management by disposal on the land. CRREL Special Report 171. AD 752132.

Ripley, E.A. (1972) Man, matador and meteorology. *Atmosphere*, vol. 10, no. 4.

Rouse, W.R. and R.G. Wilson (1972) A test of the potential accuracy of the water budget approach to estimating evapotranspiration. *Journal of Agricultural Meteorology*, vol. 9, p. 421-446, Amsterdam: Elsevier Publishing Company.

Saxton, K.E., H.P. Johnson and R.H. Shaw (1974) Watershed evapotranspiration estimated by the combination method. *Transactions of the ASAE*, vol. 17, no. 4, p. 668-672.

Shcherbakov, A.S. (1978) Method of wintertime sprinkler distribution of wastewater. CRREL Draft Translation 674.

Skaggs, R.W. (1974) The effect of surface drainage on water table response to rainfall. *Transactions of the ASAE*, vol. 17, no. 3, p. 406-411.

Threadgill, E.D. and D.B. Smith (1975) Effects of physical and meteorological parameters on the drift of controlled size droplets. *Transactions of the ASAE*, vol. 18, no. 1, p. 51-56.

U.S. Army (1965) Pavement design for frost conditions. Technical Manual 5-818-2, Headquarters, Washington, D.C.

U.S. Army (1966) Calculation methods for determination of depths of freeze and thaw in soils. Technical Manual 5-852-6, Headquarters, Washington, D.C.

U.S. Army Tropic Test Center (1972) Evaporimetry in the canal zone. Part I. Climatological measurements of evaporation. Technical Research Note, U.S. Army Test and Evaluation Command, Fort Clayton, Canal Zone.

U.S. Department of Agriculture (1964) *Irrigation*. Section 15, chapter 1, Soil plant-water relationships, Soil Conservation Service National Engineering Handbook, Washington, D.C.

U.S. Department of Commerce (1955) Evaporation from pans and lakes. U.S. Weather Bureau Research Paper no. 38.

U.S. Department of Commerce (1956) Seasonal variation of the probable maximum precipitation east of the 105th meridian for areas from 10 to 1,000 square miles and durations of 6, 12, 24 and 48 hours. U.S. Weather Bureau Hydrometeorological Report no. 33.

U.S. Department of Commerce (1958) Climatic summary of the U.S. — Supplement for 1931 through 1952, New England. Climatography of The U.S. No. 11-23, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce (1959) Evaporation maps for the United States. U.S. Weather Bureau Technical Paper no. 37.

U.S. Department of Commerce (1959) Rainfall intensity — frequency regime. Part I. The Ohio Valley, Part II. Southeastern U.S., Part III. The Middle Atlantic Region, and Part IV. Northeastern U.S. U.S. Weather Bureau, Technical Paper no. 29.

U.S. Department of Commerce (1964) Climatic summary of the U.S. Supplement for 1951 through 1960. New England. Climatography of the U.S. No. 86-23. U.S. Government Printing Office, Washington, D.C.

U.S. EPA (1977) Process design manual for land treatment of municipal wastewater. U.S. Environmental Protection Agency, Office of Water Program Operations. EPA 625/1-77-008.

Veihmeyer, F.J. (1964) Evapotranspiration. In *Handbook of Applied Hydrology* (V.T. Chow, Ed.), Section 11. New York: McGraw-Hill.

Van Bavel, C.H.M., K.J. Brust and G.B. Stirk (1968) Hydraulic properties of a clay loam soil and the field measurements of water uptake by roots. Part 2. The water balance of the root zone. *Proceedings, Soil Science Society of America*, vol. 32, p. 317-321.

Whiting, D.M. (1976) Use of climatic data in estimating storage days for soil treatment systems. Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA-600/2-76-250.

October 1972

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean*	Dew Point Mean (°F)	Speed (MPH)	Wind** Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	54	33	43	98	32	68	33	5	NNW+SSE	10	.03	
2	65	32	48	98	40	83	43	2	Var	3		
3	70	42	56	100	46	85	51	2	Var	3		
4	75	47	61	100	46	87	57	3	WSW	3		
5	69	46	58	100	41	86	54	2	SW	3		
6	64	44	54	100	60	85	50	3	ENE+WSW	7		
7	57	53	55	100	92	99	55	4	NE	5	1.71	
8	60	48	54	91	33	63	42	5	NW	9		
9	46	38	42	88	51	57	28	6	NW	8		T
10	50	28	39	100	25	53	23	5	NW	7		
11	60	26	43	100	30	73	35	4	SW	7		
12	56	42	49	100	78	92	47	3	SW+N	5	.07	
13	44	27	35	100	38	69	26	4	NNW	6		
14	46	26	36	100	62	93	34	2	N+WSW	5	.13	T
15	42	26	34	100	41	68	25	6	NW	11		
16	46	25	36	100	67	80	30	5	SSW	8		
17	50	34	42	100	39	64	31	6	WNW	11		
18	40	22	31	100	36	72	23	2	NNW	5		
19	38	26	32	100	48	74	25	4	ENE+N	6		
20	38	21	30	100	33	70	21	2	Var	6		
21	44	16	30	100	36	71	22	2	WSW	5		
22	42	34	38	100	74	85	38	2	WSW+N	3	.09	
23	46	38	42	100	100	100	42	2	NNE	4	.06	
24	56	38	47	100	58	88	44	4	NE+WNW	8		
25	38	33	35	100	62	81	30	4	NW+NE	10		
26	49	29	39	100	37	77	32	2	SSW	7		
27	60	24	42	100	23	75	35	1	Var	7		
28	50	26	38	100	82	96	37	1	Var	7	.20	
29	50	34	42	100	76	96	41	4	NNW	11	.62	
30	38	26	32	100	56	70	23	9	NNE	22		
31	43	24	39	100	44	77	32	2	Var	3	—	—
Ave. Monthly	51	33	42	100	23	77	36	3	WNW and SW	Max22	Total 2.91	T

Monthly Max = 75°F Monthly Min = 16°F T = Trace

*Mean: Arithmetic mean for 24 hrs

**Winds during Oct and Nov taken from upper level - Trailer wind instrumentation not installed.

November 1972

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth*
1	44	32	38	96	53	74	30	4	SSW	5		
2	46	40	43	100	79	95	42	3	SW	4		
3	54	36	45	100	52	85	41	6	NW	14		
4	37	30	34	100	56	89	31	4	ENE	6	.10	1
5	36	31	34	100	100	100	34	1	Var	3	.22	2
6	43	32	38	100	67	86	34	2	SW+NE	4		0
7	39	32	36	96	82	93	34	3	WSW	5		
8	44	34	39	96	82	89	36	5	E	10	.90	
9	42	37	40	94	68	83	35	8	N	9	.11	
10	43	28	36	100	64	79	30	5	N	8		
11	38	28	32	100	86	97	31	2	WSW+NE	5	.11	
12	40	34	37	98	85	90	34	2	SW	4		
13	44	38	41	100	84	94	39	2	WSW	4		
14	40	30	35	100	82	97	34	5	NE	7	.38	0
15	30	26	28	100	70	87	25	6	NNE	8	.11	4
16	32	12	22	98	52	74	15	5	NNW	8		7
17	26	11	14	99	77	94	13	2	NNE	4		7
18	42	19	30	98	49	88	27	2	SE+NNW	3		7
19	36	15	26	98	70	92	24	3	S+NNE	4		6
20	38	31	34	100	57	81	29	5	NW	12	.90	6
21	30	22	26	60	44	53	11	6	N	8		4
22	26	9	18	86	40	62	7	5	N	9		4
23	26	6	16	86	42	68	7	4	WNW+SSE	9		4
24	36	20	28	86	70	78	22	4	WNW	8		4
25	37	32	34	98	65	80	28	4	WSW+SE	8		4
26	56	34	45	100	70	89	42	7	NNW+SE	12	.70	3
27	45	38	42	84	56	62	30	9	WSW	15		3
28	36	29	32	100	70	93	30	3	SW+NE	5	.30	1
29	34	18	26	100	58	86	22	4	W	9		1
30	26	13	19	100	55	93	17	2	E	3	.35	4
Ave.Monthly	38	26	32	100	40	84	28	4	W+NE	15	4.18	Max = 7

Monthly Max = 56°F   Monthly Min = 6°F

*Snow depth data taken from the following sources:
1. Nov 1972-Feb 1973 from Hanover, N.H. Co-Op sta.
2. Mar and Apr 1973 from Lebanon, N.H. FAA sta.
3. Dec 1973-Mar 1974 from USA CRREL Met. sta.

December 1972

Date	Temperature (°F) Max	Temperature (°F) Min	Temperature (°F) Ave	Rel. Hum. % Max	Rel. Hum. % Min	Rel. Hum. % Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Wind Dir.	Wind Max Hourly	Precipitation (in) Amt.	Precipitation (in) Snow Depth
1	30	21	26	100	54	86	22	6	SW	15	.37	10
2	24	7	16	100	51	75	9	3	NNE	8		9
3	32	13	22	100	68	90	20	4	NNE	9		9
4	17	10	14	100	61	92	12	3	NNE	5	.65	13
5	25	16	20	100	96	91	18	4	SSW	9	.22	17
6	38	25	32	100	60	95	31	3	W	8	.48	13
7	32	-2	15	98	28	48	-1	4	NNE	8		12
8	22	-6	8	100	85	96	7	Calm		3	.33	14
9	29	22	26	100	95	97	25	2*	NE	5	.10	14
10	34	28	31	100	95	97	30	3*	Var	11	.08	13
11	28	1	14	96	37	69	6	4	NE	7		13
12	18	-4	7	100	81	95	6	1	Var	3	.21	14
13	40	21	30	100	46	72	22	5	WSW	13	.05	13
14	31	11	21	98	50	82	16	2	NNE	7		13
15	16	3	10	96	77	92	8	3	NE	7	.45	16
16	26	8	17	100	56	79	11	5	W+ENE	11	.21	21
17	7	-8	0	100	60	71	-7	7	NNW	13	.05	20
18	25	-9	8	95	49	75	2	3	W	6		20
19	26	18	22	97	84	89	19	2	W	5		20
20	26	14	20		m		m	4	E	6	.05	20
21	17	11	14	100	90	96	13	3	SW	5	.25	21
22	26	17	22	100	96	98	22	2	ENE	5	.19	24
23	27	20	24		m		m	1	Var	2		20
24	30	26	28		m		m	1	Var	4		20
25	36	29	32		m		m	2	NNW+ESE	4		20
26	37	35	36	100	76	98	35	3	SW	5	.16	20
27	34	23	28	100	74	88	25	1	Var	6	.01	19
28	31	22	26	100	66	87	23	2	NNE	6	.05	20
29	23	8	16	78	56	68	7	4	NNE	7		20
30	24	15	20	100	73	89	17	4	NE+S	8	.24	20
31	34	24	29	100	92	98	28	3	WSW	7	.43	21
Ave.Monthly	27	14	20	100	28	86	16	3	NE+W	15	4.58	Max = 24

Monthly Max = 40°F   Monthly Min = -9°F

*(Winds from Lower Level on Roof, Surface Wind Sta. Inoperative.)

m = missing

January 1973

Date	Temperature (^oF) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (^oF)	Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	46	34	40	100	52	79	34	4	WSW+E	8	.10	17
2	38	27	32	70	48	57	18	6	WNW	8		16
3	34	17	26	95	54	72	18	*4	NNE	6		16
4	38	18	28	100	64	90	25	5	ESE+NW	11	.25	18
5	40	25	32	98	48	65	22	6	WNW	15		17
6	23	-2	10	74	52	59	-1	*10	NNE	19		17
7	4	-12	-4	67	44	53	-17	*8	N	15		17
8	0	-22	-11	82	41	59	-21	4	NNE	8		17
9	14	-20	-3	94	42	73	-10	1	Var	3		17
10	26	-5	10	98	50	80	5	2	NW	8		17
11	28	-3	12	98	48	72	5	3	WNW	8		17
12	23	2	12	98	44	71	4	3	NNE+WNW	6		17
13	24	-6	9	98	45	82	5	1	NE	2		17
14	32	6	19	99	58	81	14	2	WNW+NE	5		17
15	40	24	32	98	68	88	29	2	NNE+NW	3		16
16	46	28	37	98	54	76	30	4	NNE+WSW	12		16
17	55	24	40	98	44	80	34	2	NE+WSW	5		15
18	50	32	41	99	64	88	38	2	WSW	5		15
19	52	28	40	98	61	86	36	3	W	11	.23	13
20	42	18	30	100	61	87	27	3	N+NW	m	.62	11
21	27	9	18	90	52	62	7	2	N+NNE	7	T	10
22	38	2	20	98	59	77	14	3	NNE	5		10
23	41	38	40	100	62	85	36	4	WNW	9	.75	9
24	38	21	30	96	60	75	23	5	W+N	9		9
25	32	12	22	90	37	64	12	2	NW+NE	5		8
26	37	22	30	99	64	83	25	3	NNE	6		8
27	32	21	26	98	82	95	25	3	NNE	6		8
28	30	22	26	100	44	85	22	3	NE+ESE	5	.05	9
29	26	0	13	100	66	81	8	6	N	11	.81	19
30	18	-18	0	94	58	69	-8	6	WSW+NE	11		18
31	8	-22	-7	97	45	66	-12	7	N	11		18
	32	10	21	100	37	75	14	4	WNW+NE	19	2.81	Max = 19

Monthly Max = 55^{o}F   Monthly Min = -22^{o}F
*Used Roof Wind Lower Level
T = Trace

February 1973

Date	Temperature (°F) Max	Temperature (°F) Min	Temperature (°F) Ave	Rel. Hum. % Max	Rel. Hum. % Min	Rel. Hum. % Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Wind Dir.	Wind Max-Hourly	Precipitation (in) Amt.	Precipitation (in) Snow Depth
1	6	-22	-8	88	64	81	-12	4	W	5		18
2	30	6	18	100	84	98	17	4	WNW	7	.94	18
3	38	23	30	100	66	77	24	7	WNW	12		12
4	33	16	24	98	60	72	16	6	WNW	13		12
5	35	12	24	72	42	58	11	7	NNE	15		12
6	28	-2	13	98	42	68	7	3	NNW	5		11
7	32	19	26	83	58	63	10	5	ENE+W	7		11
8	31	16	24	100	76	92	22	3	W	5	.06	11
9	14	-7	4	83	46	61	-6	6	NNE	12		11
10	18	-14	2	97	44	72	-5	5	N	12		11
11	12	-8	2	68	41	56	-10	9	NNE	13		11
12	8	-10	-1	84	62	72	-8	6	NNE	12		11
13	26	6	16	98	62	76	10	5	N	11		10
14	42	4	23	99	29	66	13	4	NNE	6		10
15	36	30	33	100	84	94	31	4	NW+S	6	.28	13
16	28	5	16	92	66	74	9	9	N	15		13
17	8	-11	-2	73	42	56	-14	7	NNW	11		13
18	26	-18	4	98	42	72	-3	2	N	6		13
19	36	-3	16	99	52	78	10	4	WNW+NE	14		13
20	45	30	38	99	56	84	34	4	W+NE	10		11
21	42	30	36	100	56	89	33	3	NE	5	.12	12
22	37	27	32	100	78	87	29	4	NE	9	.06	12
23	29	23	26	88	60	72	18	6	N	10		12
24	29	9	19	99	35	60	7	4*	N	10		12
25	25	7	16	76	36	52	1	7*	N	15		11
26	30	6	18	85	36	50	2	6*	NE	13		11
27	22	1	12	98	42	59	0	1	ENE	9		11
28	33	-5	14	99	41	76	8	3	NNE	6		11
	28	6	17	100	29	72	9	5	NNW	15	1.46	Max = 18

Monthly Max = 45°F   Monthly Min = -22°F

*Upper Level Wind used.SFC wind equipment out of operation.

March 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	45	14	30	97	55	76	23	3	NE+SSW	5		6
2	42	29	36	93	72	89	33	3	NNE	6		5
3	35	32	34	94	88	91	31	4	SE	5		4
4	48	32	40	93	76	88	37	3	WNW	7		4
5	50	32	41	96	46	77	34	3	NE	8		3
6	40	30	35	98	60	70	26	5	SW	7		3
7	38	32	35	98	87	93	33	4	SSW	6		3
8	57	35	46	99	76	91	43	2	SW	4	.40	2
9	48	31	40	95	46	79	34	2	NE	6		2
10	42	31	36	92	40	54	21	4	SE	6		1
11	41	35	38	98	64	78	32	3	SW	4	.10	1
12	59	39	49	95	51	73	41	4	W	9		T
13	49	27	38	88	36	56	24	4	N	8		T
14	40	25	32	94	50	77	26	2	NE	3		T
15	40	28	34	98	42	65	24	3	SE	6	.05	T
16	57	30	44	96	42	69	34	3	WNW	6	.42	T
17	48	36	42	92	80	88	39	3	S	4	.53	0
18	39	27	33	89	50	64	22	3	SW	6		
19	40	30	35	68	58	63	24	6	NW	12		
20	35	26	30	74	60	67	20	5	NNW	9		
21	38	20	29	94	52	67	19	2	ENE	4		
22	44	33	38	64	49	56	24	5	ENE	7		
23	50	27	38	76	31	46	19	8	NE	16		
24	58	29	44	100	26	63	32	4	NNW	6		
25	63	25	44	100	39	70	35	2	Var	5		
26	45	38	42	100	67	92	40	5	ENE	8	.28	
27	45	26	36	92	21	49	19	6	NNE	12		
28	52	20	36	98	19	56	22	4	SSW	6		
29	52	27	40	99	23	62	28	3	SW	6		
30	53	28	41	97	42	73	33	4	WSW	6		
31	63	35	49	85	39	64	37	2	WSW	6		0
	47	29	38	100	19	71	29	4	SW+NE	16	1.78	Max = 6

Monthly Max = 63°F   Monthly Min = 14°F
Peak Gust 31 MPH on Mar 31

April 1973

Date	Temperature (°F) Max	Temperature (°F) Min	Temperature (°F) Ave	Rel. Hum. % Max	Rel. Hum. % Min	Rel. Hum. % Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Wind Dir.	Wind Max-Hourly	Precipitation (in) Amt.	Precipitation (in) Snow Depth
1	51	42	46	98	40	77	39	4	NE	7	.61	0
2	42	31	36	100	75	89	33	4	ENE	7	.64	0
3	40	31	36	100	62	86	32	2	SE+SW	3	.11	1
4	43	31	37	100	60	84	33	3	S	4	.72	0
5	38	30	34	100	54	75	27	3	NW	7	.20	3
6	46	34	40	58	38	45	20	6	NW	15		T
7	50	32	41	56	25	37	17	6	NNE	12		0
8	46	27	36	79	28	48	18	4	N	12		0
9	46	24	35	82	23	46	16	3	N	6		0
10	37	32	34	100	66	91	32	3	N	10	.72	1
11	33	26	30	98	58	75	23	6	SE	13		4
12	38	18	28	98	28	57	15	6	SE	11		3
13	39	22	30	74	39	53	15	7	S	13		2
14	53	20	36	98	21	63	25	4	S+W	6		T
15	64	25	44	98	18	56	29	5	N	9		0
16	76	30	53	100	18	53	36	5	N	12		
17	68	44	56	82	30	50	37	4	ENE	13		
18	72	41	56	98	39	73	47	5	ENE	13		
19	73	40	56	100	24	52	38	3	SW	8		
20	68	30	49	96	16	50	31	2	ESE	3		
21	73	38	56	96	38	56	41	2	NE	5		
22	82	49	66	100	40	69	56	2	NNW	3	.08	
23	69	48	58	77	39	58	43	3	NE+WNW	4		
24	66	42	54	98	46	70	44	2	W	3		
25	64	43	54	96	29	57	39	3	N	4		
26	52	43	48	98	54	73	40	2	SSE	3	.03	
27	46	43	44	100	82	94	42	3	NE	8	.17	
28	59	44	52	100	93	99	52	2	W	5	.59	
29	44	38	41	95	70	81	36	3	NW	5		
30	54	35	44	98	66	85	40	3	NE	4		0
	54	34	44	100	16	67	33	4	N+SE	15	3.87	Max = 4

Monthly Max = 82°F Monthly Min = 18°F
Peak Gust 34 MPH on 6 Apr.

May 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in.) Amt.
1	71	35	53	100	62	82	48	3	NNE	5	
2	75	52	64	100	74	91	61	2	S	3	
3	76	54	65	100	86	97	64	2	SSW	4	.37
4	54	42	48	96	60	78	41	3	WNW	4	
5	50	40	45	100	66	88	42		Calm	3	
6	54	41	48	96	66	82	43	3	S+NW	7	
7	69	32	50	97	38	71	41	3	W+ENE	9	
8	71	34	52	100	61	83	47	2	NW+SW	6	.03
9	54	48	51	100	100	100	51	1	Var	3	.38
10	75	50	62	100	66	91	59	2	WNW+SE	4	.60
11	68	50	59	100	95	99	59	2	Var	3	.46
12	64	41	52	100	83	94	50	2	WSW	m	.20
13	58	43	50	98	64	79	44	m	WNW	m	
14	52	33	42	98	56	79	36	2	NNW	7	.05
15	57	32	44	98	45	77	37	2	W	4	.26
16	59	35	47	98	34	67	36	3	NW	5	.32
17	60	31	46	98	40	67	35	3	W	9	
18	45	38	42	98	77	86	38	3	ENE	4	.20
19	46	38	42	100	60	80	36	4	WSW	7	
20	65	34	50	100	37	80	44	2	WSW	3	.40
21	54	46	50	100	90	98	49	3	NNW	3	1.21
22	56	39	48	100	69	85	44	3	NW+ESE	10	.04
23	69	37	53	98	38	75	45	3	N	5	
24	73	36	54	98	32	68	44	3	NW	4	
25	58	49	54	97	67	80	48	2	SE	3	
26	63	45	54	98	55	78	47	2	S	3	
27	69	44	56	99	46	70	46	3	SSE	4	
28	54	48	51	100	100	100	51	2	SE	3	.60
29	76	55	66	100	52	83	61	2	S	5	.03
30	75	54	64	100	46	76	56	2	SW	3	.03
31	74	54	64	100	53	79	57	2	SW+ENE	5	.05
	63	42	52	100	32	82	47	2	WNW+SE	10	5.23

Monthly Max = 76°F Monthly Min = 31°F
Peak Gust 20 MPH on 3 May.

June 1973

Date	Temperature (°F) Max	Temperature (°F) Min	Temperature (°F) Ave	Rel. Hum. % Max	Rel. Hum. % Min	Rel. Hum. % Mean	Dew Point Mean (°F)	Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in.) Amt.
1	72	44	58	97	48	78	51	2	Var	4	.18
2	63	35	49	98	28	60	36	3	NW	5	
3	75	31	53	100	26	66	42		Calm	2	
4	70	42	56	100	76	94	54	2	N	3	
5	76	60	68	98	76	92	66	3	NE+S	6	
6	79	60	70	98	66	89	67	3	SE	4	.03
7	86	60	73	98	43	78	66	4	SW	6	.03
8	84	54	69	98	46	74	60	4	W+SSE	6	.01
9	84	56	70	98	45	80	64	4	WSW	6	.01
10	82	52	67	98	43	71	57	4	WNW+S	7	.01
11	91	61	76	100	47	74	67	3	S	8	.54
12	81	61	71	100	68	92	68	3	S	7*	.41
13	73	58	66	100	73	96	65	3	SE	8	.35
14	72	50	61	98	32	70	51	4	WNW+SSE	12	T
15	60	41	50	98	42	70	41	3	NE	15	
16	52	48	50	100	84	96	49	4	SE+NE	9	.63
17	66	46	56	98	45	72	47	4	NE	10	
18	65	42	54	98	72	91	51	3	W+ENE	8	
19	79	54	66	98	52	80	60	3	NE	6	.02
20	82	53	68	98	50	82	62	5	WNW	12	
21	84	67	76	98	73	94	74	3	WNW	6	.29
22	79	66	72	100	72	94	70	2	WNW	6	.79
23	79	62	70	98	60	86	65	3	W	6	
24	80	60	70	98	64	89	67	3	SE	7	
25	76	57	66	99	66	89	63	2	NW	6	T
26	78	57	68	99	55	84	63	3	NW+S	9	T
27	74	62	68	97	68	89	65	2	Var	7	.19
28	76	62	69	98	69	88	65	3	NW	10	.54
29	76	67	72	99	77	95	70	4	SE	13	.67
30	70	62	66	100	97	99	66	3	NW+NE	6*	1.74
	75	54	65	100	26	84	60	3	NW+SE	15	6.44

Monthly Max = 91°F Monthly Min = 31°F
Peak Gust 12 Jun 25 MPH.
*Trailer Wind Speed Recorder Inoperative; Upper Level Winds Used from 12-30 June.

July 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in.) Amt.
1	80	61	70	100	59	86	65	3*	NNE+SE	7	
2	82	61	72	100	63	86	67	3	SE	9	
3	80	56	68	100	66	87	64	4	SSE	9	
4	68	61	64	100	93	99	64	2*	SSE+NNE	5	.71
5	74	56	65	100	48	87	61	3*	SE+NE	8	.09
6	80	50	65	100	46	74	57	5*	W+SE	19	
7	86	53	70	100	41	79	63	5*	W	13	
8	94	61	78	100	45	77	70	3*	W	8	
9	90	64	77	100	42	79	70	4*	W	8	.12
10	78	57	68	100	44	80	62	4*	WNW	7	
11	71	46	58	100	41	64	46	9*	W+NE	21	
12	63	41	52	100	36	66	41	9*	N	24	
13	78	39	58	100	56	73	49	4	SSE	10	.02
14	84	60	72	100	47	77	64	5	SSE+NE	14	.38
15	74	59	66	100	70	92	63	4	SE+W	9	.04
16	80	52	66	100	41	77	58	3	NW	7	
17	79	47	63	100	43	75	55	3	NW	6	
18	79	51	65	100	35	80	59	2*	NW	4	
19	84	50	67	100	35	75	59	2*	ESE	4	
20	82	57	70	100	48	80	63	4	SW+NNE	9	
21	79	54	66	100	52	86	62	3	NNE	5	
22	82	50	66	100	33	69	55	5*	N	14	
23	83	47	65	100	34	68	54	4*	NE	10	
24	88	51	70	100	32	66	58	5*	N	18	
25	87	54	70	100	36	72	61	3*	SW	7	
26	77	58	68	100	69	89	65	6*	W	15	
27	85	68	76	100	65	91	73	5*	SW	17	.38
28	90	67	78	100	43	72	68	10*	SSW	24	
29	80	60	70	100	57	83	65	4*	SW	10	
30	88	60	74	100	40	78	67	4*	SE+NW	8	
31	86	60	73	100	46	79	66	4*	NE	12	
	81	53	68	100	32	79	61	4	W+SE	24	1.74

Monthly Max = 94°F Monthly Min = 39°F
Peak Gust = 31 MPH on 28 July.
*Upper Level Winds used.

August 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in.) Amt.
1	83	60	72	99	55	83	67	4	NE+SE	6	.13
2	72	68	70	98	95	98	70	2	W	3	.69
3	86	68	77	98	54	84	72	3	SSW	3	
4	83	60	72	99	41	77	65	4	W	6	
5	85	56	70	100	33	75	61	6*	NW+SE	10	
6	88	54	71	100	49	85	66	4	NE+SW	8	
7	85	62	74	100	48	81	68	5*	SSW	8	
8	83	64	74	99	50	82	68	3*	SSW	6	
9	87	65	76	99	54	82	70	3*	SSW	6	
10	91	67	79	98	43	79	72	4	SW	11	.10
11	78	65	72	100	68	89	68	4	SW	7	
12	80	63	72	100	49	84	67	4	SW	8	
13	75	55	65	100	60	85	60	5	NNW	8	
14	74	55	64	99	61	88	60	5	NW+SE	10	
15	63	58	60	98	94	98	60	4	NW+SE	5	.07
16	79	54	66	98	48	81	60	4	NNE	6	
17	84	53	68	98	40	80	61	3	Var	4	
18	85	56	70	99	42	79	63	3	NNE	5	
19	79	56	68	100	45	82	62	3	NE	5	
20	81	53	67	100	47	85	62	3	W	7	
21	78	54	66	100	48	83	61	3	S	6	
22	70	53	62	98	66	90	59	4	SSW	8	.06
23	73	44	58	98	36	73	50	3	Var	6	
24	72	47	60	98	35	74	52	4	N	8	
25	77	45	61	98	37	75	53	3	NW	6	
26	77	55	66	100	58	88	62	3	NE	5	
27	88	62	75	100	58	88	71	4	SSW	6	.05
28	87	62	74	100	38	80	67	5	SW	10	.18
29	92	59	76	100	39	76	68	5	SW	14	
30	93	65	79	99	37	78	71	7	SW	17	
31	93	65	79	99	43	86	75	8	SSW	12	1.47
	81	58	70	100	33	83	64	5	SW	17	2.75

Monthly Max = 93 Monthly Min = 44
Peak Gust = 42 MPH on 30 Aug.
*Upper Level Winds Used.

September 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in.) Amt.
1	86	63	74	100	54	90	71	3	m	4	
2	90	67	78	100	55	87	74	m	m	m	
3	91	68	80	100	46	83	74	4	m	6	
4	82	65	74	100	47	82	68	4	m	6	
5	80	63	72	100	63	86	67	8	SE	12	T
6	74	52	63	100	55	86	59	8	SSW	10	.64
7	66	46	56	100	37	73	47	8	SW	18	T
8	57	40	48	96	49	73	40	5	SW	8	
9	56	38	47	97	47	72	38	8	m	16	
10	70	36	53	100	33	66	42	6	W	12	
11	76	40	58	100	35	77	51	6	SW	12	
12	66	44	55	100	38	74	47	7	NW*	15	
13	68	40	54	100	38	75	46	6	NW*	14	
14	56	43	50	100	74	94	48	3	WSW	4	.32
15	59	42	50	100	77	94	48	4	W	7	.01
16	65	42	54	100	54	78	47	8	W	15	
17	64	35	50	100	37	80	44	6	NW+SE	7	.01
18	61	41	51	100	75	91	48	6	WNW	8	.68
19	66	36	51	100	33	80	45	4*	S	5	
20	61	33	47	100	55	75	40	6*	W	12	
21	63	25	44	98	28	72	36	8*	WNW	11	
22	51	25	38	100	94	99	38	5	SW	9	.52
23	71	50	60	100	36	82	55	6	WNW	13	
24	53	48	50	100	70	83	45	4	E	8	
25	63	44	54	100	43	77	47	2	Var	4	
26	67	42	54	100	45	86	50	2	SE	4	
27	73	48	60	100	50	86	56	2	SW	4	
28	66	41	54	99	31	62	41	4	NNW	7	
29	65	39	52	100	40	71	43	5*	W	9	
30	61	34	48	100	28	69	38	5*	N	10	
	68	44	56	100	28	72	49	5	SW	18	2.18

Monthly Max = 91 Monthly Min = 25
Peak Gust = 45 MPH 12 Sep 73
*Upper Level Winds Used.

October 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in.) Amt.
1	72	33	52	100	29	88	48	2*	SW	4	
2	74	36	55	100	65	89	52	4*	SW	6	
3	65	58	62	100	95	99	62	4*	W	5	.33
4	72	56	64	100	60	88	60	4*	NNW	5	.54
5	67	38	52	99	44	82	47	5	SW	11	.26
6	62	33	48	100	18	65	37	7*	N	15	.44
7	67	29	48	100	28	77	41	3*	ENE	5	
8	66	29	48	100	25	77	41	3	NNW	5	
9	68	32	50	100	22	75	42	3	NE	4	
10	54	34	44	100	54	81	39	6*	m	8	
11	61	35	48	100	35	77	41	m	m	m	
12	72	34	53	100	31	77	46	3*	W	6	
13	71	38	54	100	52	78	47	3	SSW	7	
14	59	41	50	97	35	59	36	8	SSW	16	.06
15	63	33	48	100	21	64	37	8	WNW	11	
16	49	30	40	100	43	69	31	4	W	12	
17	46	30	38	98	43	70	29	4	WNW	10	
18	44	28	36	98	57	87	33	2*	SW	5	.06
19	52	27	40	98	29	73	32	3*	SW	7	
20	44	36	40	100	75	87	36	3*	WSW	5	.06
21	56	26	41	100	29	63	29	5*	NE	12	
22	63	23	43	100	37	82	38		Calm	8	
23	69	30	50	100	39	78	43	2	SSW	4	
24	76	32	54	100	28	76	47	2	WSW	3	
25	52	43	48	100	73	85	44	2	SE	4	
26	61	40	50	100	54	83	45	2	Var	3	
27	50	25	38	100	44	65	27	6	NW	11	
28	47	19	33	98	35	64	22	3	ESE	5	
29	51	32	42	95	55	73	34	4	ENE	8	.05
30	61	41	51	100	83	91	48	5	ENE	11	.59
31	62	34	48	100	35	84	43	3	ESE	8	
	60	34	47	100	18	78	41	4	W	16	2.39

Monthly Max = 76°F Monthly Min = 19°F
*Upper Level Winds Used
Peak Gust = 41 MPH, 14 Oct 73

November 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Dir.	Max-Hourly	Precipitation (in.) Amt.
1	50	34	42	98	50	82	37	5	NNE	14	.60
2	57	43	50	98	33	51	33	7	WSW	12	.04
3	47	36	42	98	33	54	27	8	W	17	.17
4	40	21	30	87	31	44	11	6	WNW	14	
5	38	18	28	98	30	58	15	4	SSW	7*	
6	28	19	24	87	41	57	11	5	W	9*	
7	27	16	22	97	40	70	14	4	Var	8*	
8	41	23	32	97	41	67	22	3	SW	7*	.02
9	36	21	28	97	31	49	11	5	SE+NW	9	
10	31	18	24	99	46	62	13	6	NW	10	
11	37	17	27	99	32	70	18	4	SE	8	
12	40	21	30	92	54	71	22	4	SW	7	
13	45	36	40	79	53	60	27	3	SW	5	
14	64	40	52	85	37	61	39	4	SW	11	
15	44	31	38	100	96	99	38	2	NE	7	.37
16	43	30	36	100	53	79	30	5	NW	8	.36
17	36	25	30	64	45	53	15	5	SW	9	
18	43	28	36	87	35	58	23	4	SW	7	
19	39	23	31	90	40	72	23	3	NW	7	
20	34	15	24	100	55	72	16	4	N	9	
21	42	14	28	100	50	75	21	3	S	5	.03
22	46	37	42	99	89	97	41	1	Var	2	.07
23	44	34	39	99	80	97	38	1	Var	3	
24	39	31	35	99	99	99	35	2	NE	3	.17
25	49	33	41	99	64	78	35	7	NW	13	.08
26	45	22	34	84	31	67	24	3	N	6	
27	37	29	33	98	71	89	30	4	SE	9	.40
28	43	37	40	98	89	97	39	3	S	6	.26
29	46	32	39	98	46	59	26	5	S	10	T
30	39	26	32	96	60	75	25	4	S	8	.02
	40	27	34	100	30	71	25	4	WSW+S	17	2.59

Monthly Max = 64°F Monthly Min = 14°F
Peak Gust = 35 MPH 2 Nov 73
*Upper Level Winds Used.

December 1973

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	31	29	26	75	47	55	12	9	NNW	11		
2	29	16	22	88	36	59	10	4	NNW	8		
3	37	14	26	100	56	85	22	2	Var	5	T	
4	44	20	32	100	67	88	29	1	Var	2		
5	61	33	47	99	83	96	46	2	Var	11	.50	
6	61	34	48	96	43	59	34	4	S	10		
7	35	15	25	90	46	62	14	5	N	10		
8	26	13	20	98	66	88	17	1	Var	2		
9	46	19	32	99	85	95	31	4	Var	7	.35	
10	46	26	36	100	56	80	30	3	S	7		
11	33	24	28	100	60	82	23	3	N	7		
12	30	13	22	91	36	59	10	6	NNW	12		
13	33	13	23	96	42	67	14	3	Var	10	T	
14	39	26	32	100	70	92	30	3	NNW	12	.81	
15	23	13	18	70	58	65	8	8	NNW	13		
16	20	13	16	89	51	65	6	7	NNW	11	.08	1
17	16	12	14	96	82	90	12	6	N	14	1.23	2
18	18	7	12	94	85	88	9	5	NNW	15	.04	5
19	17	-12	2	75	52	62	-8		Calm	5		5
20	18	-1	8	100	62	86	5	3	S	7	.02	5.5
21	43	21	32	100	64	95	31	4	ENE	11	2.29	4
22	22	14	18	72	44	58	6	5	NW	8		3
23	28	17	22	93	59	74	15	3	S	10		3
24	16	3	10	90	46	69	2	5	N	10		3.5
25	26	12	19	99	61	81	14	2	N	4	.07	3.5
26	44	29	36	100	99	100	36	3	NE	8	.30	3.5
27	40	36	38	100	85	94	36	3	SSW	6	.54	3.0
28	42	25	34	100	45	79	28	4	SSW	8	.12	3.0
29	42	23	32	100	48	81	27	2	SSW	6		2.0
30	42	23	32	87	33	50	15	6	SSW	12		2.0
31	24	20	22	98	48	87	20	2	N	4	.35	4.0
	33	17	25	100	36	77	19	5	NNW+SSW	15	6.70	Max = 5.5

Monthly Max = 61°F   Monthly Min = -12°F
Peak Gust = 34 MPH 30 Dec 73

January 1974

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Wind Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	33	24	28	99	58	86	24	2	SSW	3		4.5
2	25	13	19	92	41	64	9	2	N	5	T	4.5
3	24	14	19	97	56	80	14		Calm	2	T	3
4	31	14	22	99	46	78	16	2	Var	3		3.5
5	27	13	20	99	38	76	14	2	Var	3		3.5
6	27	13	20	98	50	80	15		Calm	2		3.5
7	29	13	21	99	41	67	12	3	SSW	5		3.5
8	18	13	16	79	29	49	0	3	N	5		3.5
9	14	6	10	98	70	89	7	2	NE	4	.08	5
10	16	7	12	99	97	99	12	2	NE	3	.12	9
11	22	12	17	99	67	94	16	2	Var	3	.26	11
12	22	-1	10	90	32	60	-1	2	NW	5		11
13	18	-16	1	92	34	66	-8	2	NW	4		10.5
14	24	-19	2	91	43	70	-6	2	S	5		10
15	36	22	29	92	47	69	20	5	NE	9	T	9
16	21	9	15	93	69	80	10	6	NE	10	.08	9
17	10	-17	-4	74	28	50	-18	8	NNW	15	.01	9
18	8	-23	-8	88	40	64	-18	2	ENE	4	.05	8.5
19	29	1	15	95	40	69	7	6	NNE	17	.12	8.5
20	22	-8	7	93	32	65	-2	3	NE	8		9
21	34	20	27	97	74	86	23	5	S	9	.50	8
22	42	25	34	93	39	64	23	7	WSW	10		7.5
23	40	23	32	100	61	83	27	3	S	8	.14	6
24	37	26	32	74	37	56	18	3	S+NE	5		6
25	41	16	28	100	35	73	20	3	S	9		5
26	46	17	32	100	33	73	24	3	SE	7	.09	5
27	56	34	45	100	38	70	36	9	SW	22	.12	4.5
28	43	30	36	100	45	72	28	3	SW+NE	7	.34	2.5
29	37	28	32	100	60	85	28	3	NW	7	.08	3
30	35	18	26	100	35	71	18	4	S	11		1.5
31	22	9	16	91	47	84	12	8	S	19	.07	0
	29	11	20	100	28	73	12	3	NNE+SSW	22	2.06	Max = 11

Monthly Max = 56°F Monthly Min = -23°F
Peak Gust = 50 MPH 27 and 31 Jan.

February 1974

Date	Temperature (^oF)			Rel. Hum. %			Dew Point	Wind			Precipitation (in)	
	Max	Min	Ave	Max	Min	Mean	Mean (^oF)	Speed (MPH)	Dir.	Max-Hourly	Amt.	Snow Depth
1	26	10	18	88	27	45	0	11	NW	15		0
2	14	6	10	60	25	44	-8	8	N	12		0
3	14	0	7	47	24	33	-16	7	N	10		0
4	18	0	9	77	34	46	-8	7	NW	9		0
5	11	-1	5	72	33	52	-9	10	N	16		0
6	25	-6*	10	96	35	53	-4	4	N	6	.02	0
7	22	9	16	91	47	80	11	4	NE	7	.22	5
8	16	-10	3	90	57	77	-3		Calm	5		6
9	18	-7	6	87	32	67	-3	3	NW	13		5
10	21	-16	2	85	35	66	-6	2	S	6		3.5
11	27	8	18	91	36	77	12	2	SW	8		3.5
12	28	-4	12	91	30	66	3	2	S	7		4
13	46	11	28	100	58	81	23	2	S	8		3.5
14	41	-5	18	85	36	59	6	9	NNW	15		2.5
15	23	-9	7	100	33	71	-1		Calm	10		1.5
16	27	-6	10	100	43	72	3		Calm	9		1
17	35	21	28	100	52	79	22	8	N	10		1
18	27	7	17	100	52	71	9	7	NW	13		0.5
19	30	6	18	100	71	95	17	3	S	7	.31	0.5
20	39	29	34	100	55	80	28	6	NNW	14	.06	5
21	42	20	31	92	33	60	19	7	NNW	9		4
22	39	25	32	100	62	96	31	4	S	10	1.39	3
23	38	20	29	100	43	62	18	9	NW	18	.04	2
24	27	10	18	84	42	59	6	6	NW	9		1
25	32	15	24	89	51	73	17	6	NNW	9		0
26	30	10	20	100	35	65	10	4	NNW	11		0
27	38	10	24	100	45	69	15	3	Var	8		0
28	46	24	35	90	46	68	26	3	Var	8		0
	29	6	18	100	24	67	8	5	NW	18	2.04	Max = 6

Monthly Max = 46^oF Monthly Min = -16^oF
Peak Gust = 39 MPH 23 Feb 74
*Strong winds to 50 MPH blew over instrument shelter - hygrothermograph broken - no humidity and dewpoint values 1-6 Feb 74.
Data obtained using Lebanon Airport Data.

March 1974

Date	Temperature (°F) Max	Min	Ave	Rel. Hum. % Max	Min	Mean	Dew Point Mean (°F)	Speed (MPH)	Wind Dir.	Max-Hourly	Precipitation (in) Amt.	Snow Depth
1	48	29	38	100	44	68	8	4	S	14		0
2	34	22	28	100	59	82	23	3	Var	6		
3	34	30	32	100	72	86	28	6	SSE	14		
4	44	33	38	100	89	99	38	2	Var	10	.11	
5	51	38	44	100	39	73	36	5	W	14	.07	
6	57	25	41	100	30	70	32	5	Var	14		
7	63	37	50	95	34	63	38	7	SSW	14		
8	43	26	34	48	40	45	15	10	NNW	17		
9	31	23	27	100	48	56	13	4	NNW	10		
10	32	23	28	100	40	69	19	10	NNW	22		
11	34	19	26	58	37	48	9	11	NW	16		
12	26	14	20	48	28	38	-2	11	NNW	18		
13	25	10	18	55	37	49	2	11	NNW	16		
14	38	20	29	66	42	51	13	10	NNW	14		
15	45	16	30	100	26	53	15	4	NNW	8		
16	36	30	33	100	70	94	31	3	S	7	.85	0
17	35	24	30	100	66	80	25	8	S	16	.72	1
18	36	22	29	100	46	70	20	5	NW	8		1.5
19	40	22	31	100	58	84	27	5	S	8		1.5
20	35	21	28	76	32	54	14	9	N	14	.47	0
21	31	20	26	100	67	91	24	4	N	8		1
22	34	12	23	100	52	72	15	5	S	12		4
23	50	9	30	100	42	76	23	6	S	18		4
24	44	22	33	100	36	75	26	6	S	10	.17	3
25	27	12	18	90	30	43	-1	5	NW	10		1
26	45	11	28	100	37	68	19	7	S	15		0
27	32	17	24	75	33	47	7	6	NW	14		0
28	25	7	16	100	33	61	5	8	NW	17		0
29	37	1	19	95	28	50	3	4	S	10		0
30	38	25	32	100	45	75	25	5	NE	11	.04	0
31	42	34	38	100	74	92	36	4	NW	7	.08	0
	39	21	30	100	26	67	20	7	NE+S	22	2.51	Max = 4

Monthly Max = 63°F   Monthly Min = 1°F
Peak Gust = 48 NNW 10 Mar 74

APPENDIX B. CHRONOLOGICAL SUMMARY OF PRECIPITATION AND SURFACE CONDITIONS AT THE CRREL LAND TREATMENT SITE DURING THE WINTER OF 1973-1974

1973	
21-22 September	Minimum air temperature fell to less than 32°F.
4 November	Average daily air temperature less than 32°F for first time.
8 November	First light snow showers — melted quickly.
21 November	Date when daily air temperature remains below 32°F.
9 December	Wastewater spray freezing on surface of test cells.
14 December	Winter so far has been mild and wet.
15 December	Ice forming on surface of some wastewater test cells.
16-17 December	First major cold wave with snow and freezing rain.
17-18 December	Snow accumulating on wastewater test cells.
18 December	Wastewater mixing with snow cover and freezing hard on test cells. Buildup of ice mounds causing some spray water to overflow sides of test cells. Last day of wastewater spraying for 1973.
20 December	All test cells frozen over; average thickness of crust layer is 3 in. in center of cells, and 1 in. at edges.
21-22 December	Snowfall of 4 in. fell on test cells, followed by 2.5 in. mixed rain and snow, freezing rain and wet snow.
24 December	Snow depth stake reads 3.5 in. with 0.5 in. of new snow on surface. Snow on test cells too hard to insert density tube.
27 December	Rain and drizzle occurred overnight, snow cover ablating due to above-freezing air temperatures. Mound of ice (and snow crust) still remains on most of test cells.
28 December	Heavy rain of short duration overnight caused more snow ablation. Average of 1.5 in. snow on ground with some bare spots.
31 December	Rain and freezing precipitation amounts abnormally high, with numerous alternating periods of freezing and thawing air temperatures during December.
1974	
3 January	New snow layer decreased in thickness from 3 to 2.5 in. Top 0.5 in. of layer remains crusty.
10 January	About 5 in. of new snowfall over the test cells.
11 January	Light snow fell during the night, 7 to 9.5 in. of snow cover over hard ice on test cells.
21-22 January	Rain and freezing rain formed thin crust on snow surface.
30 January	Test cells covered with 0-5 in. snow-ice crust, mostly residual from December spray period.
31 January	Average of 2 in. snow on ground, snow stake reading zero. Bare spots at center of test cells, maximum snow/ice depth on cells is 5 to 6 in. Most of the old frozen wastewater spray residual has melted.
4 February	Test cells nearly free of snow and ice except for 1-2 in. ice layer about 5 ft in diameter near center.
7 February	New snowfall of 4.5 in. recorded.
12 February	Approximately 2 in. new snowfall overnight, snow depth on test cells 3 to 5 in.
20 February	New snowfall of 5 in.
22 February	Freezing rain and ice pellets occurred overnight, 0.5 in. accumulation on surface.
26 February	Between 1-3 in. hard snow-crust on test cells.
1 March	Warm air temperatures melted all snow; only ice 1-3 in. thick remains on the test cells.
10 March	Freezing rain and freezing drizzle changed to light snow, all of which then melted.
21 March	Snowfall commenced in midmorning and 4 in. had accumulated by late afternoon.
22 March	Snowfall ended late on 21 March, 7- to 8-in. snowfall on test cells. Total water equivalent equals 0.65 in.
24 March	Rain occurred, patches of snow remain on ground but test cells practically free of snow.
31 March	Some light freezing rain and freezing drizzle most of the night, water equivalent including snowfall on 30th equals approximately 0.08 in., light patches of snow on ground.
10 April	Average daily air temperature of less than 32°F recorded for last time this winter.
12 April	First day average temperature at air/ground interface on test cells exceeded 32°F.
6 May	Last day during winter of 1973-74 minimum air temperature was less than 32°F.

DAT
FILM